

# ENHANCEMENT AND VISUALIZATION OF GEOPHYSICAL DATA

by

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March 6, 2013

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# Outline

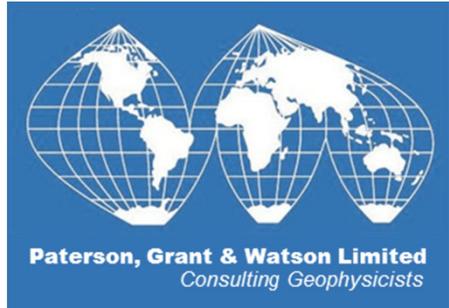
- Profile viewing
- Gridding – methods, considerations
- Imaging – colour, grey-scale, shaded relief, scaling, contours
- Filtering – space-domain, frequency-domain
- Gradient/grid-based methods – edge detection, source depths, Keating
- 3D visualization, GIS, software

# Data Types

- Magnetic (gradiometer)
- Radiometric
- Gravity (gradiometer)
- Electromagnetic (TDEM)



# Nigeria Airborne Geophysics



**All flown by Fugro  
Airborne Surveys**

**>2 million line-km**

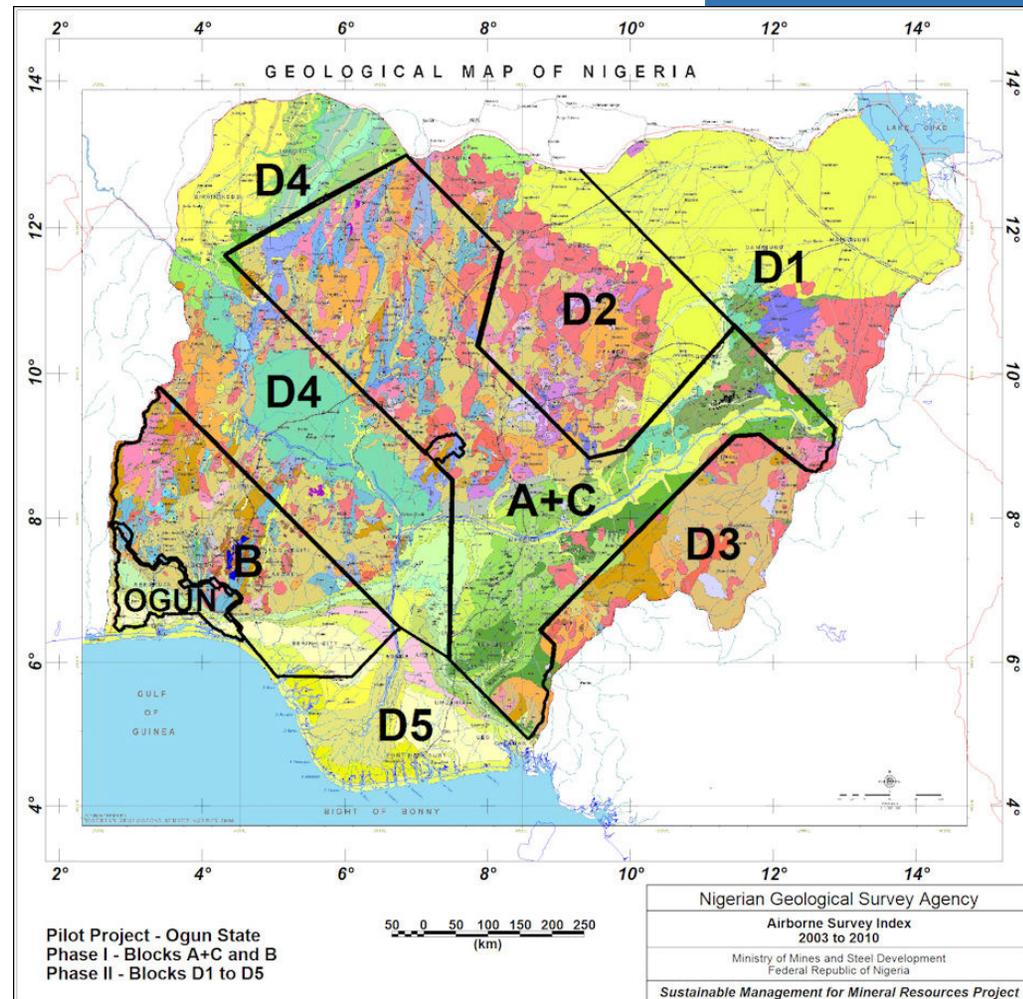
**2003 – Ogun State**

**2005-07 – A+C and B**

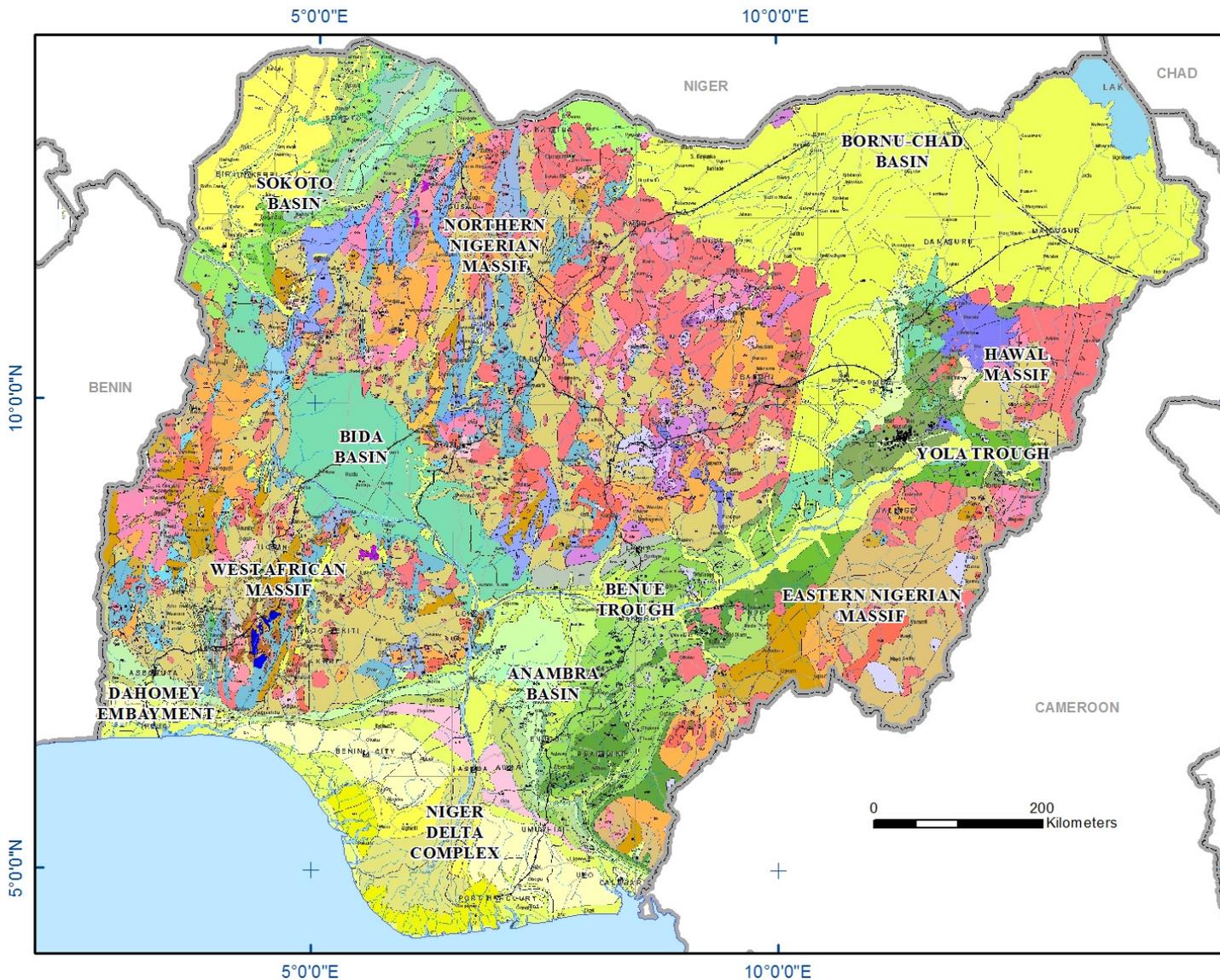
**2007-09 – D1, D2,  
D3 and D4**

**2010 – D5 (Niger Delta)**

**EM blocks in  
selected areas**



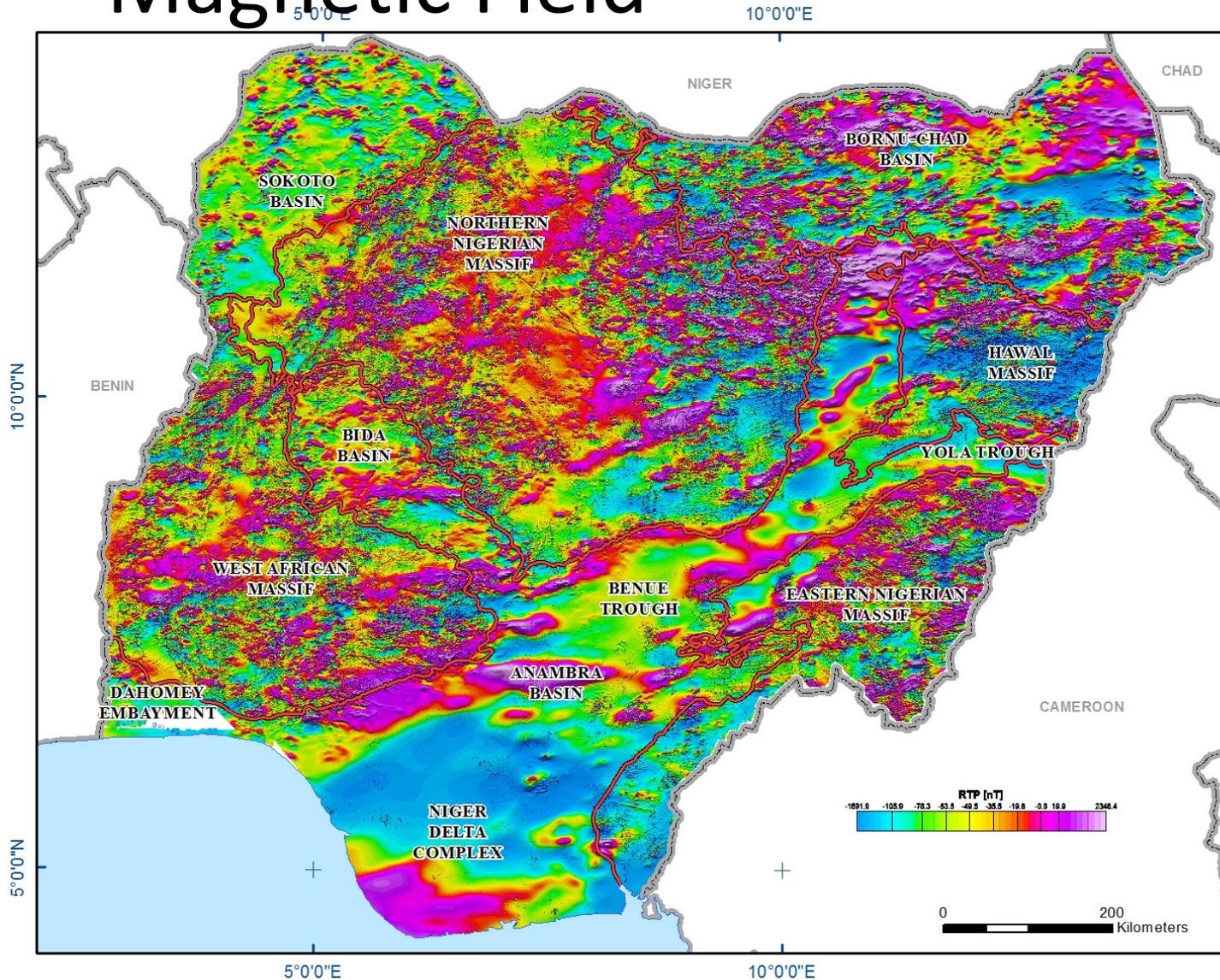
# Nigeria - Geology



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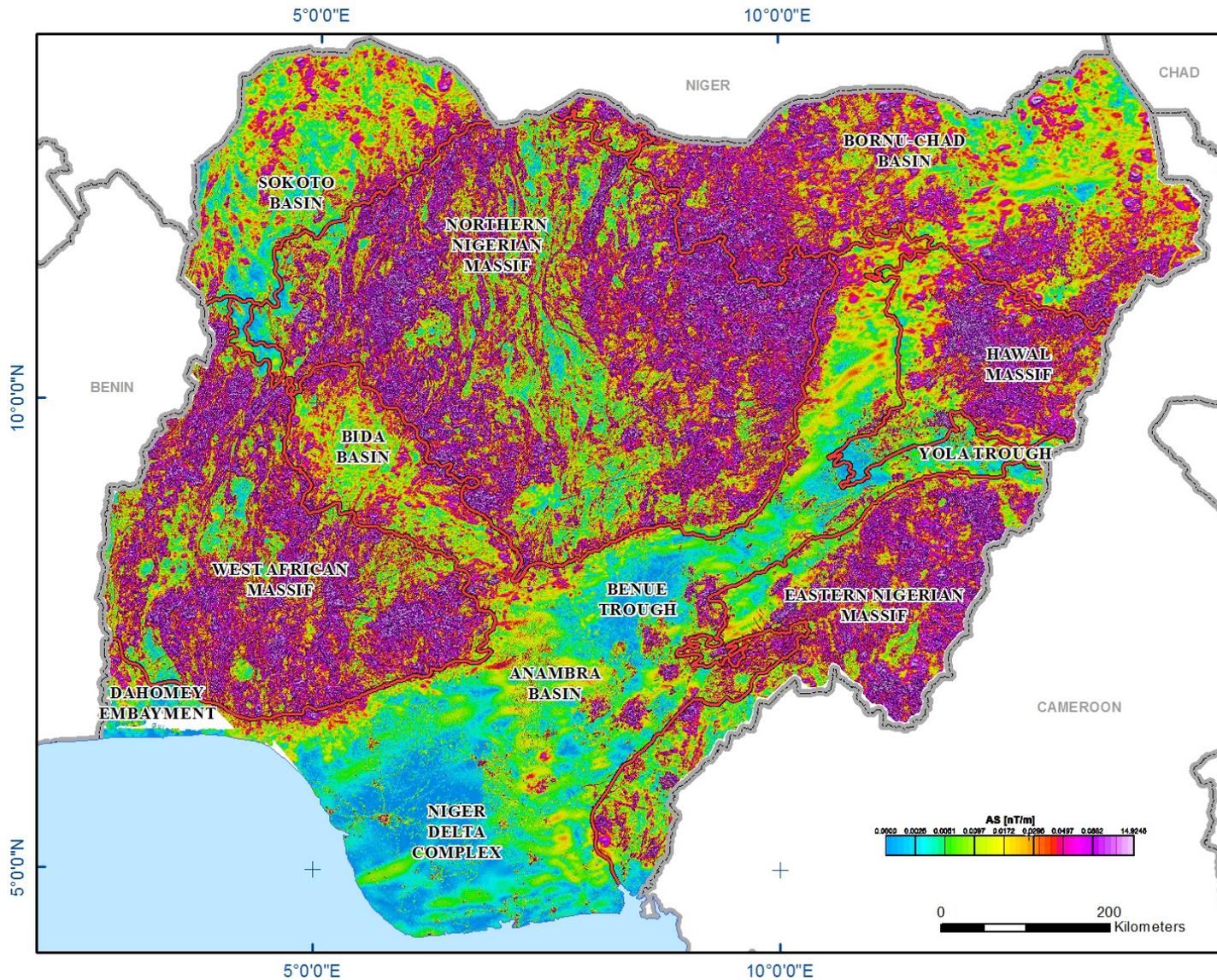
# Nigeria – Pole-reduced Magnetic Field



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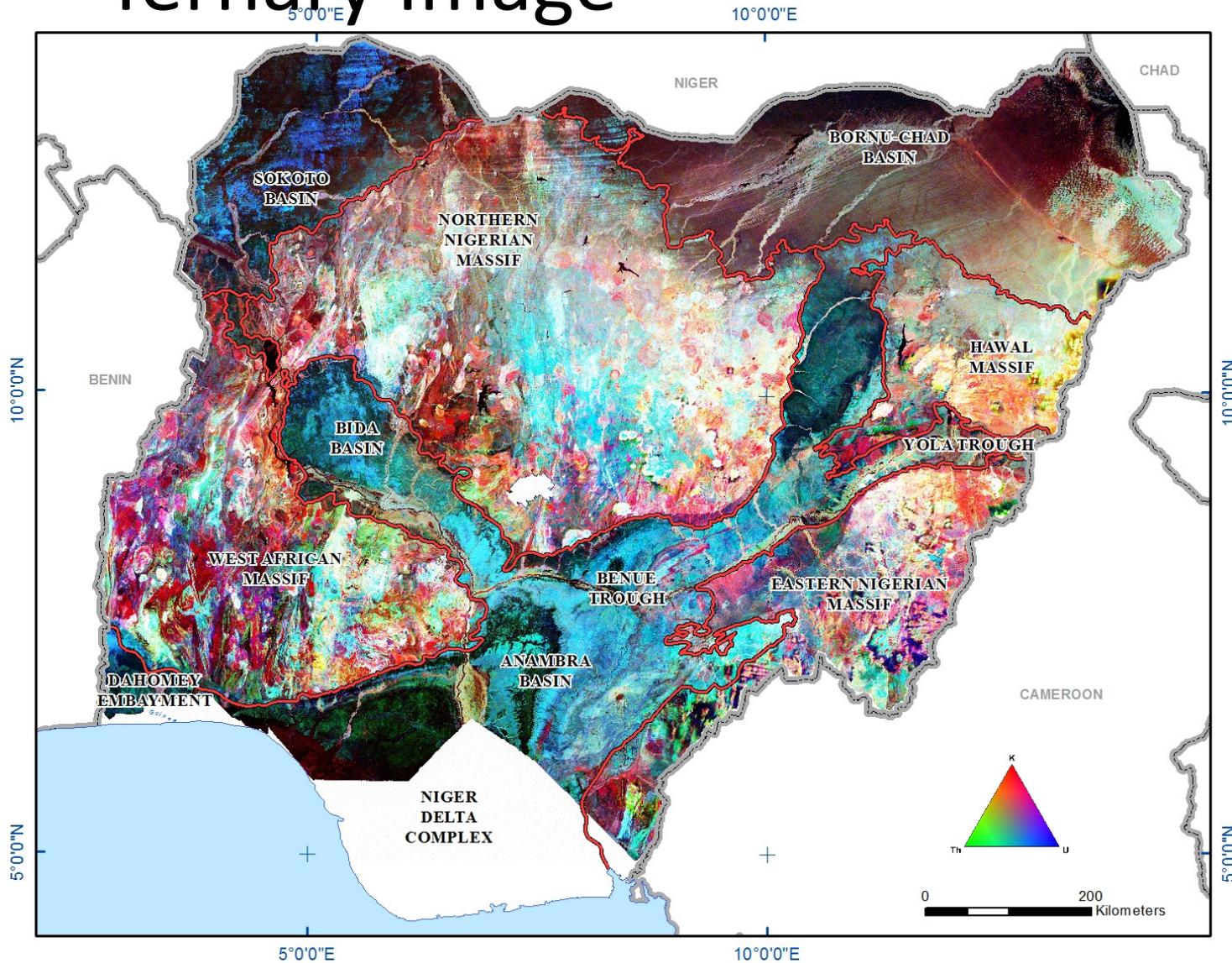
# Nigeria – Analytic Signal



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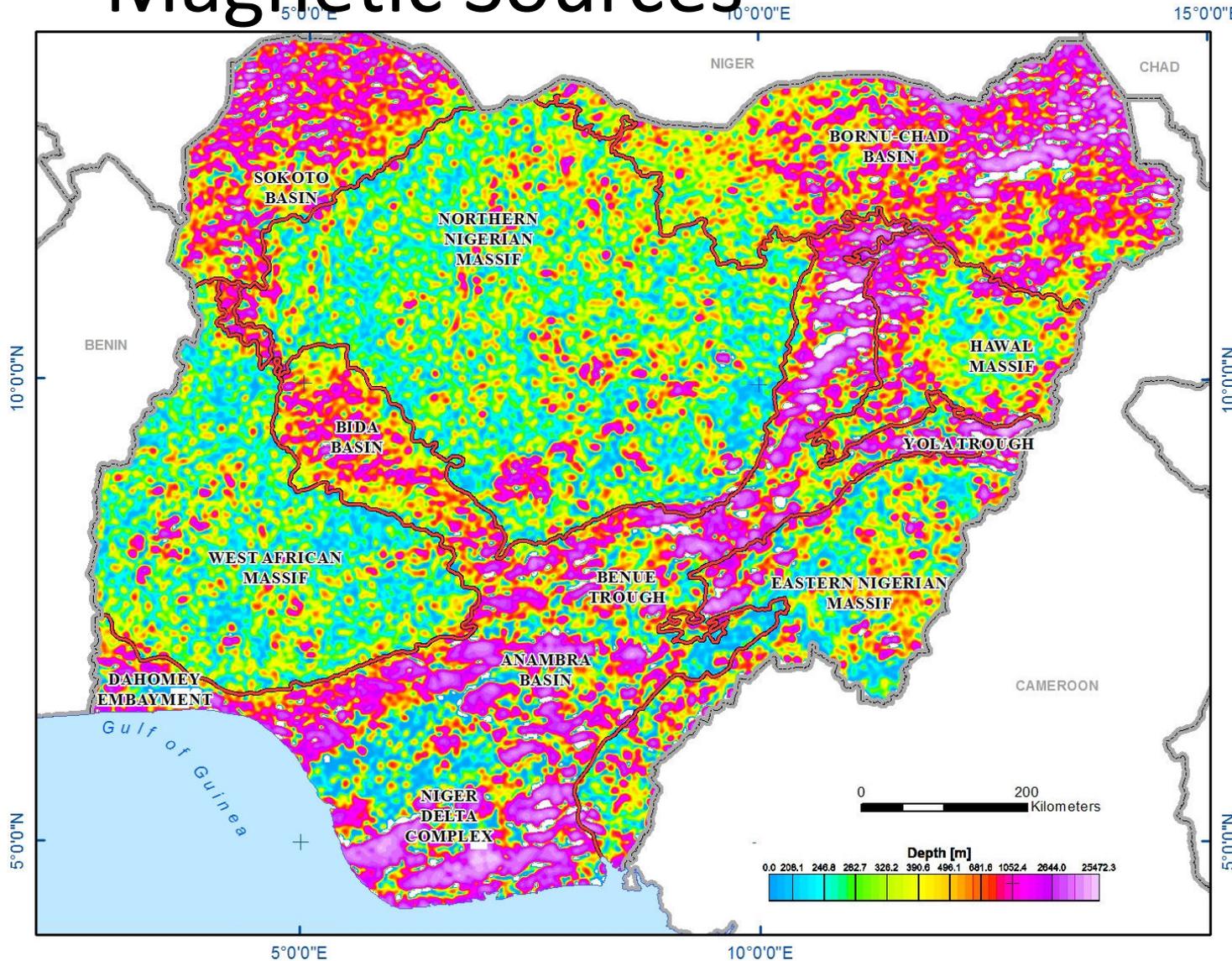
# Nigeria – Radiometric Ternary Image



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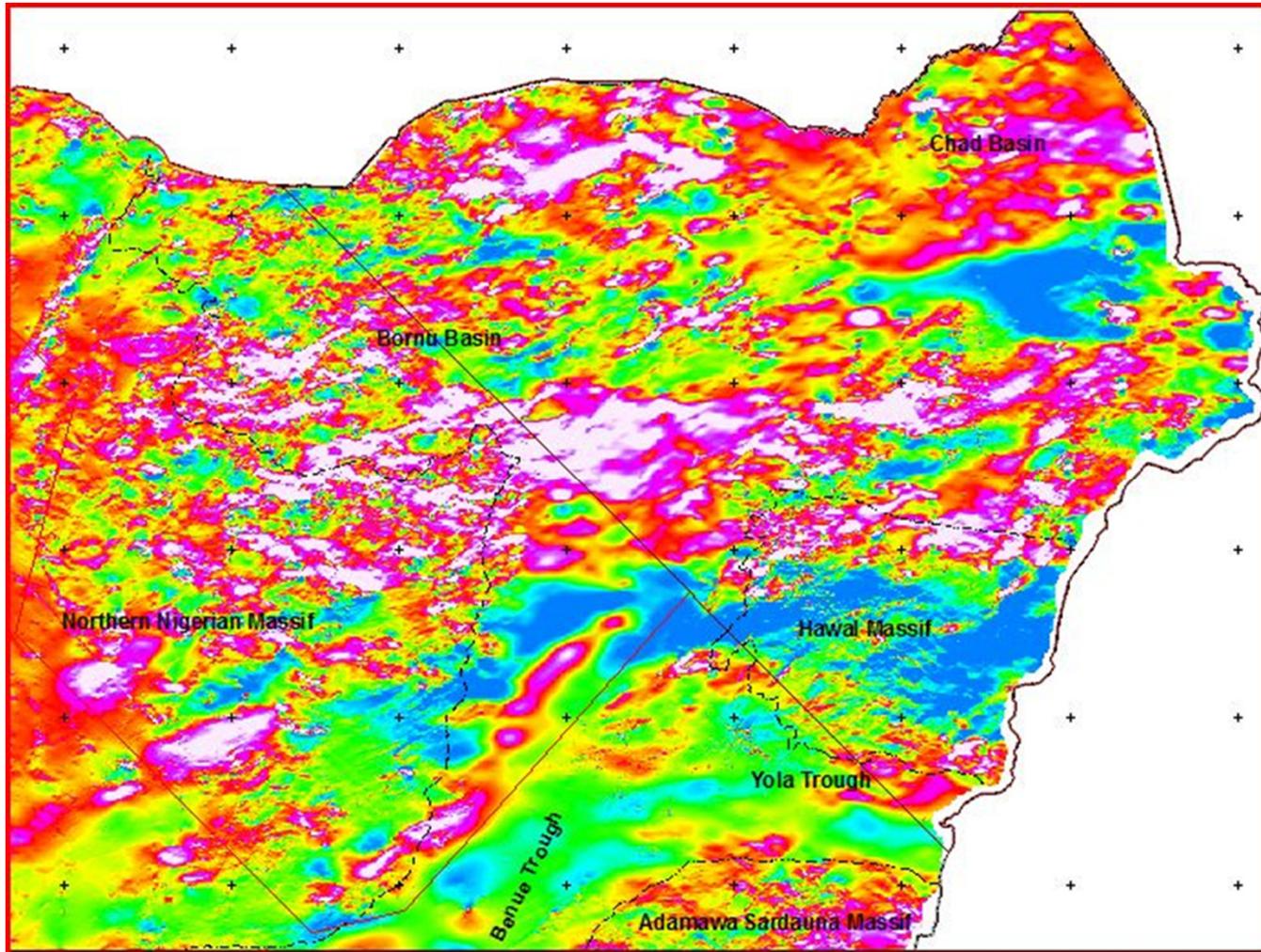
# Nigeria – SPI™ Depth to Magnetic Sources



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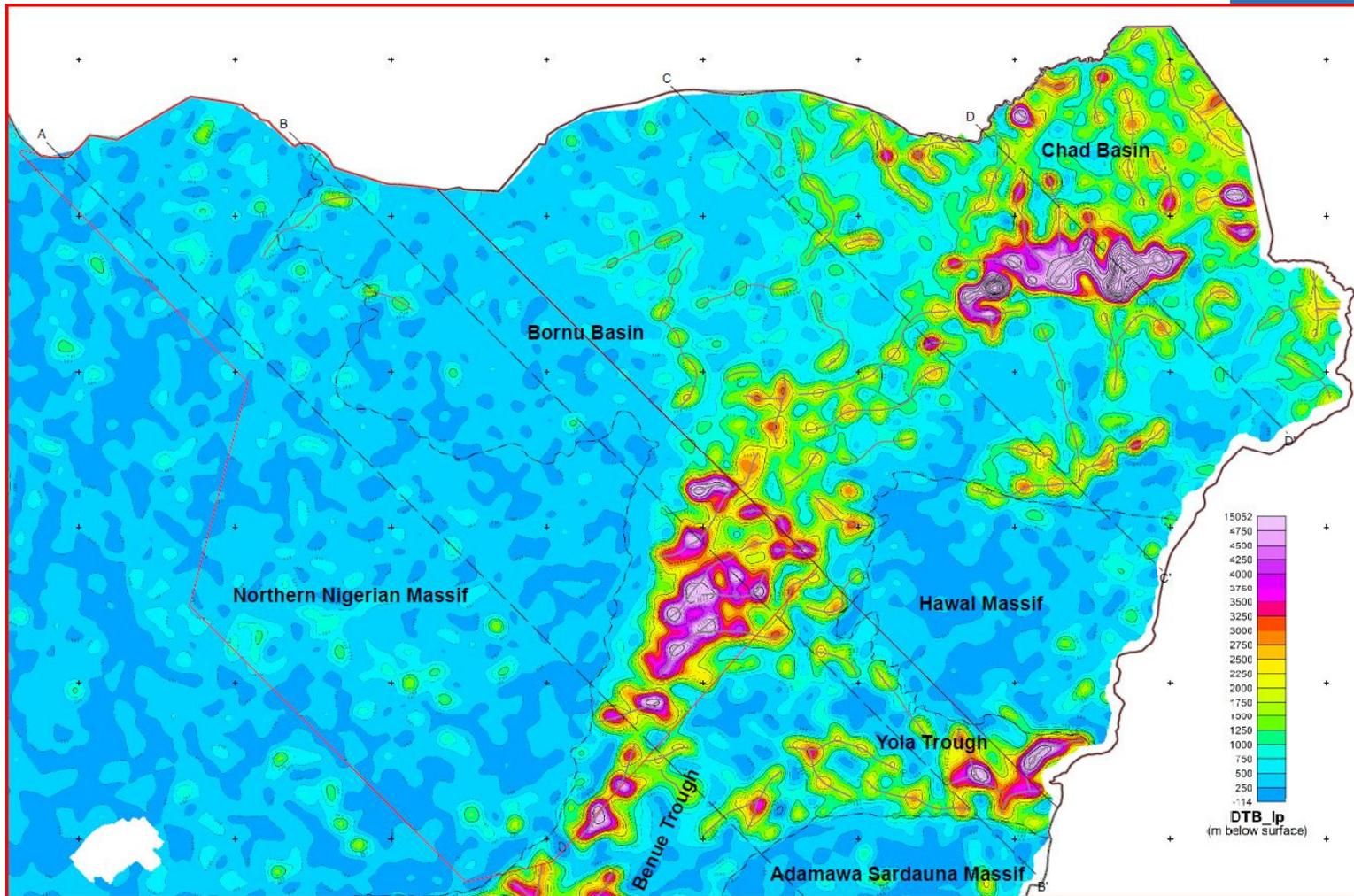
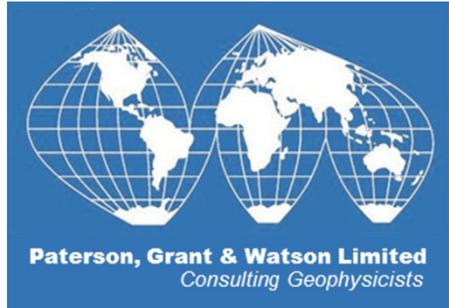
# Nigeria – SPI™ Depth to Magnetic Sources - TMI



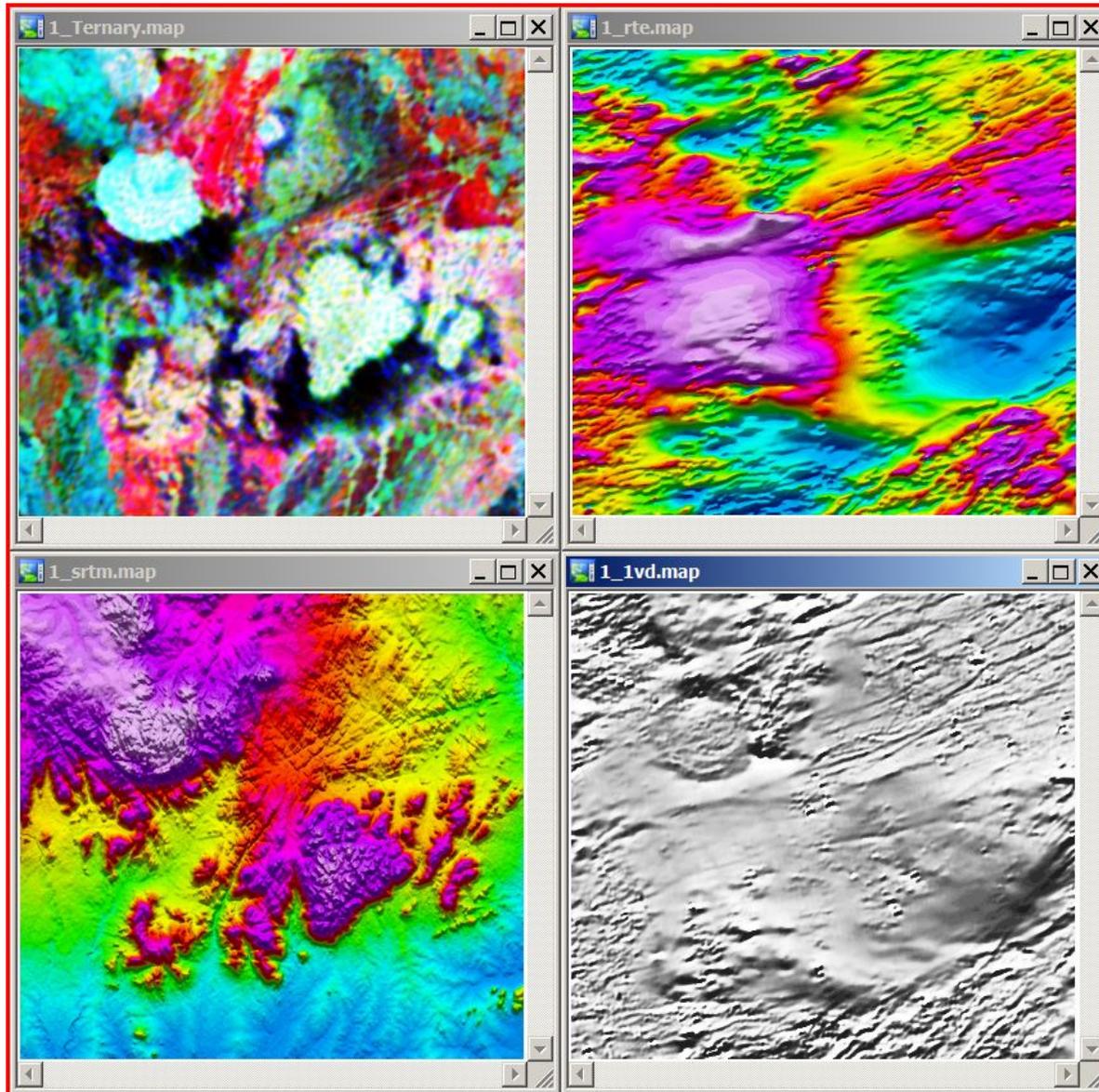
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# Nigeria – SPI™ Depth to Magnetic Sources



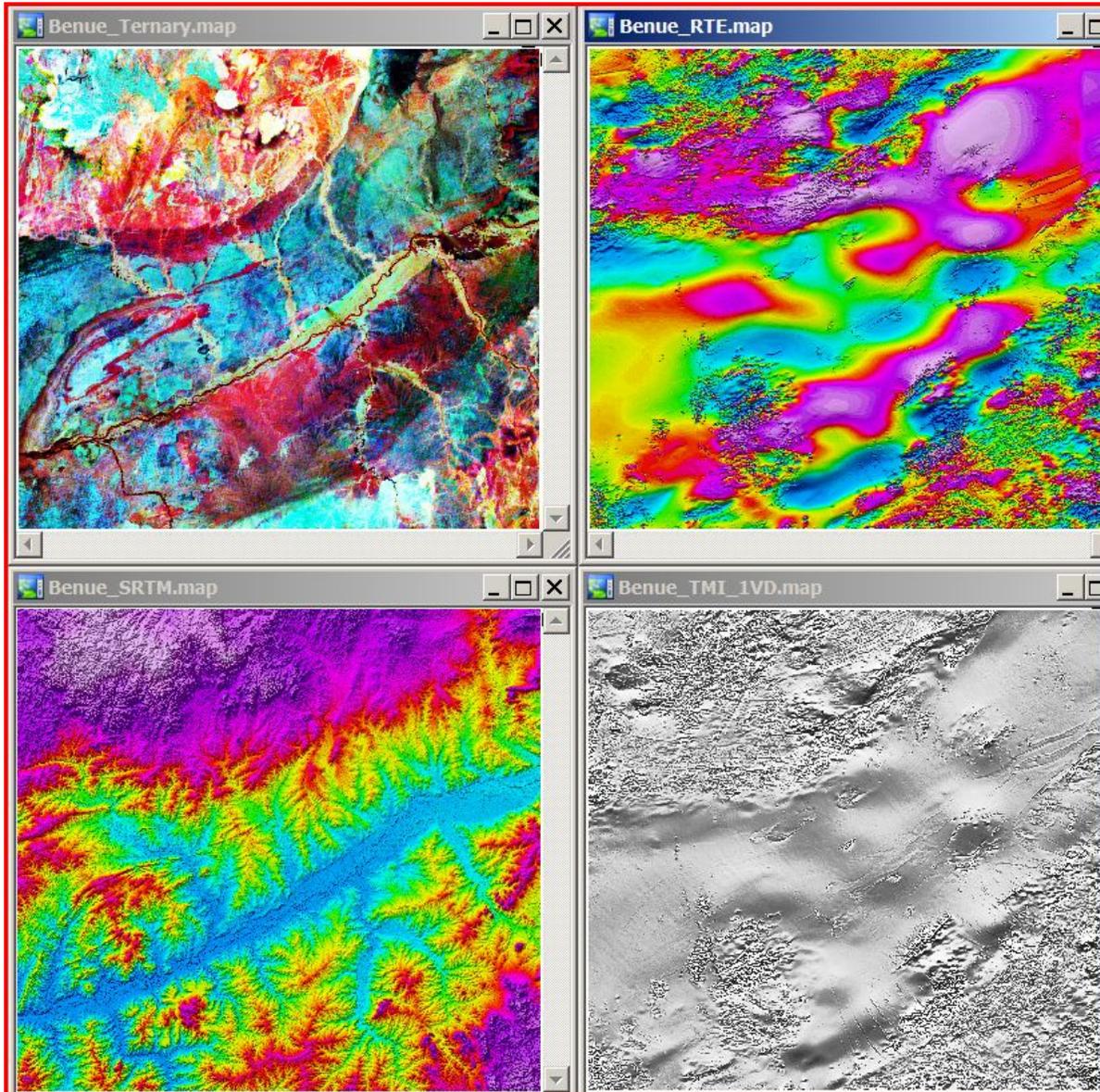
# Nigeria – Basement Responses



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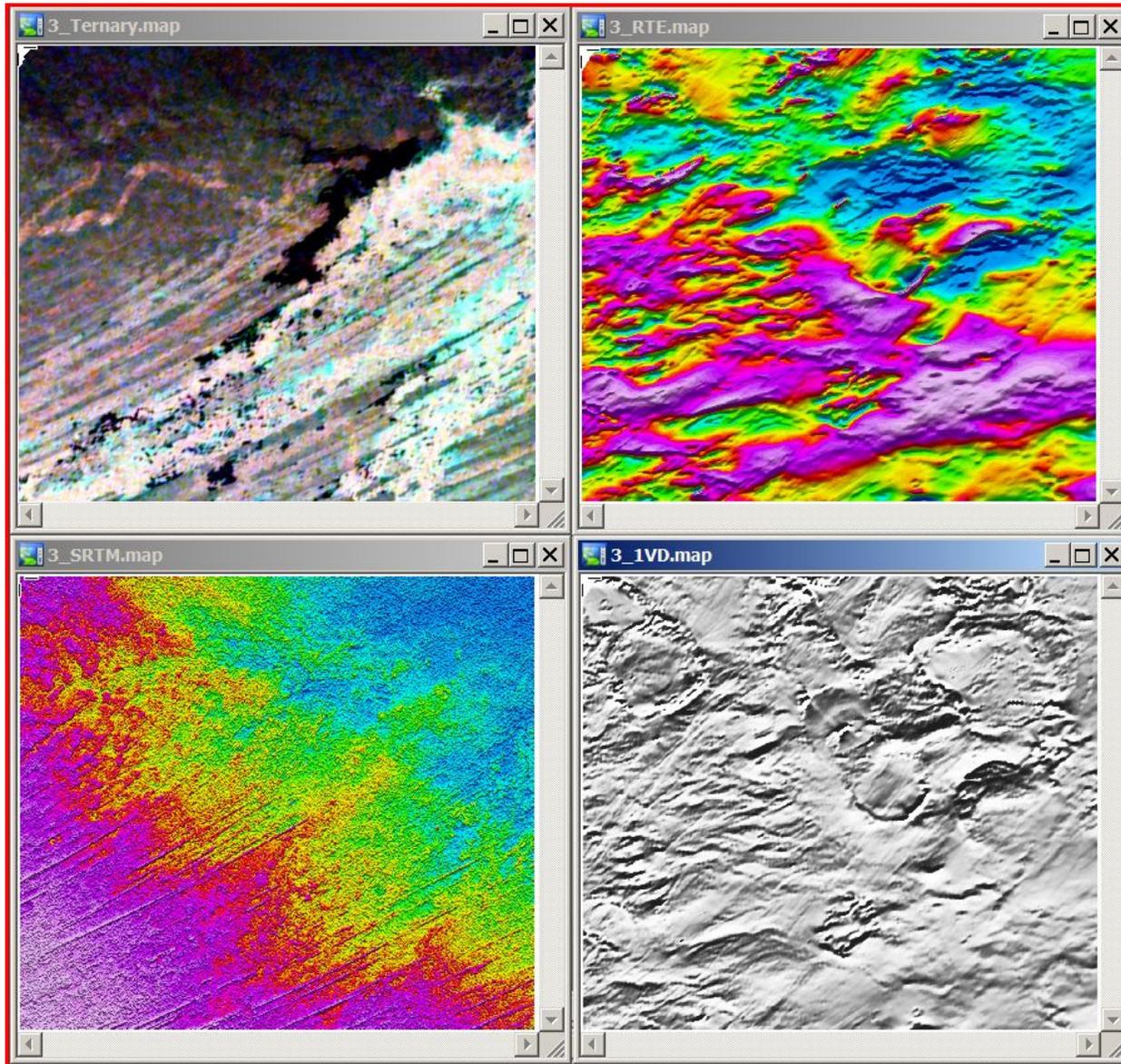
# Nigeria – Basin Responses



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# Nigeria – Shallow Basin Responses



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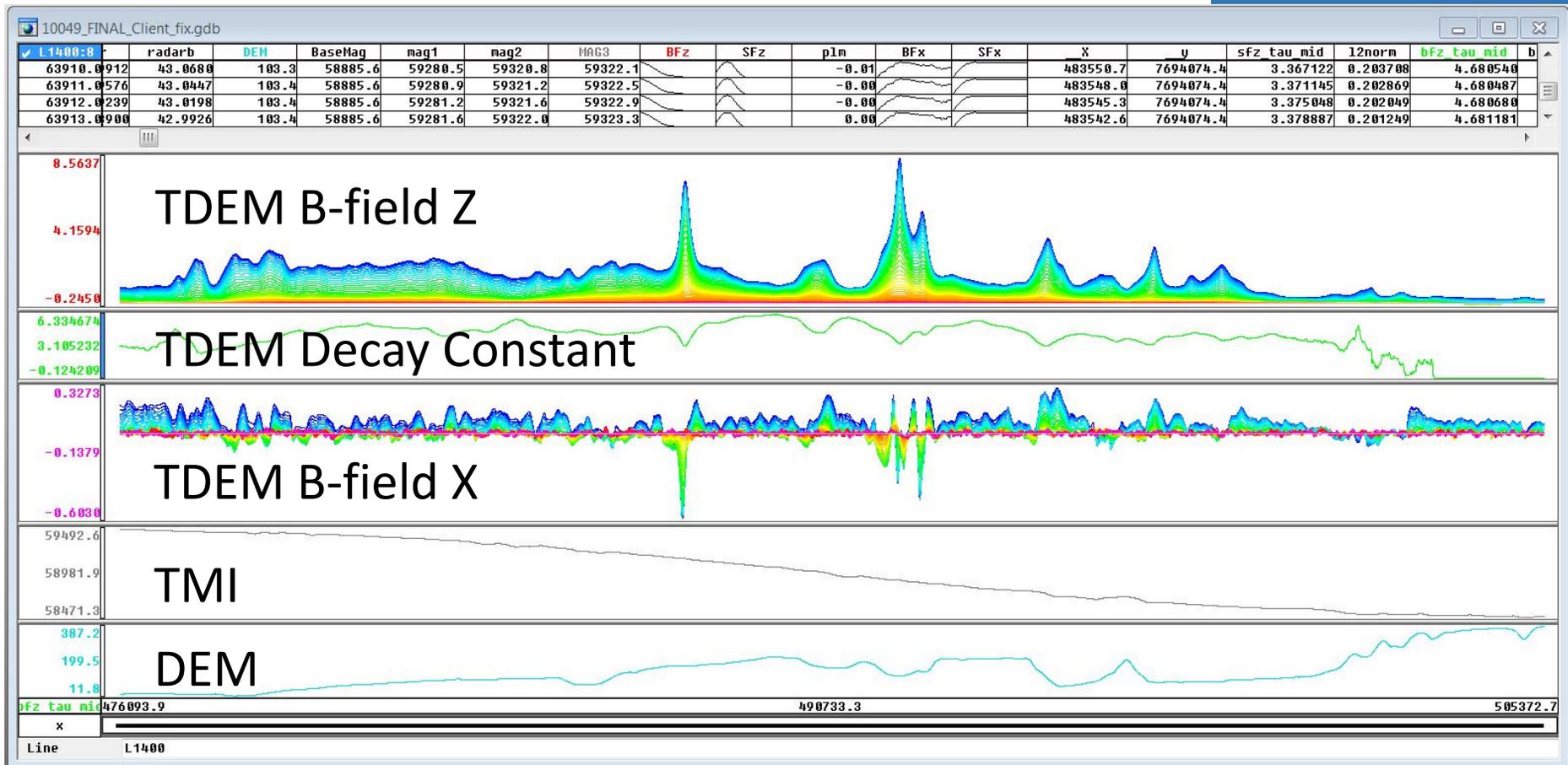
# Profile Viewing

- Data closest to its raw form – will have undergone various corrections
- Facilitates direct comparison of different data types from the same survey
- Filtering can be applied to profile data, especially magnetics – similar to grid-based methods
- Removal of noise, cultural artifacts, etc. prior to gridding
- Various modelling and depth estimation methods are profile-based

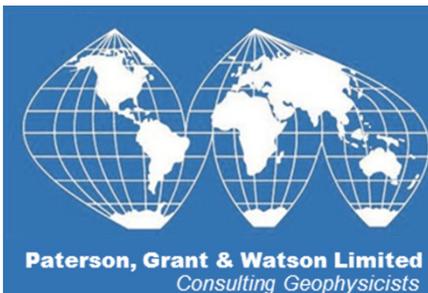


# Stacked Profile View

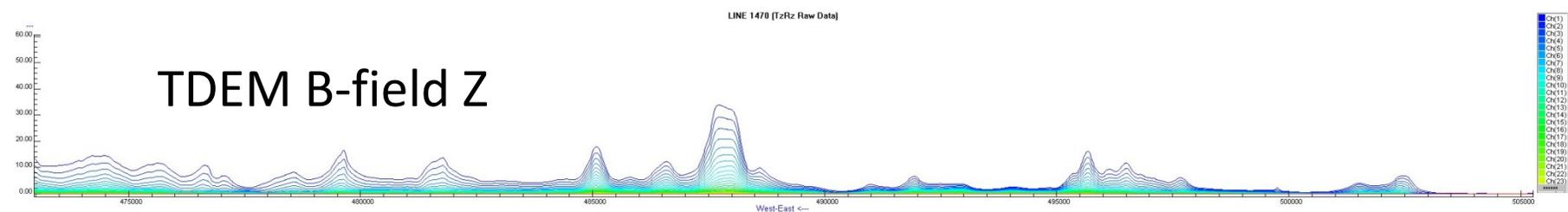
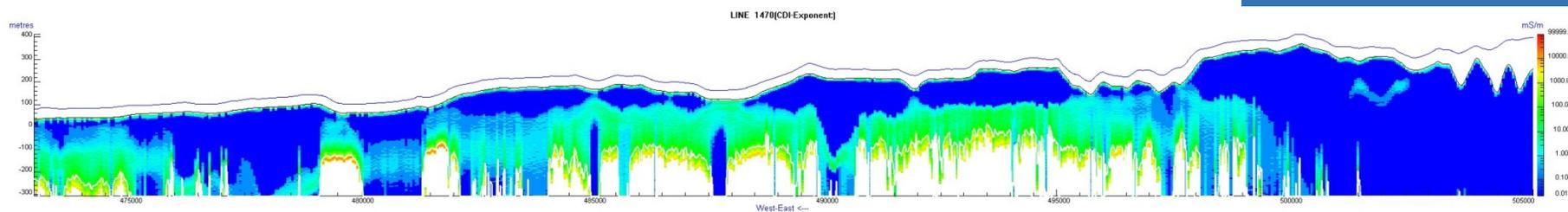
- View measured and processed data



# Profile Modelling



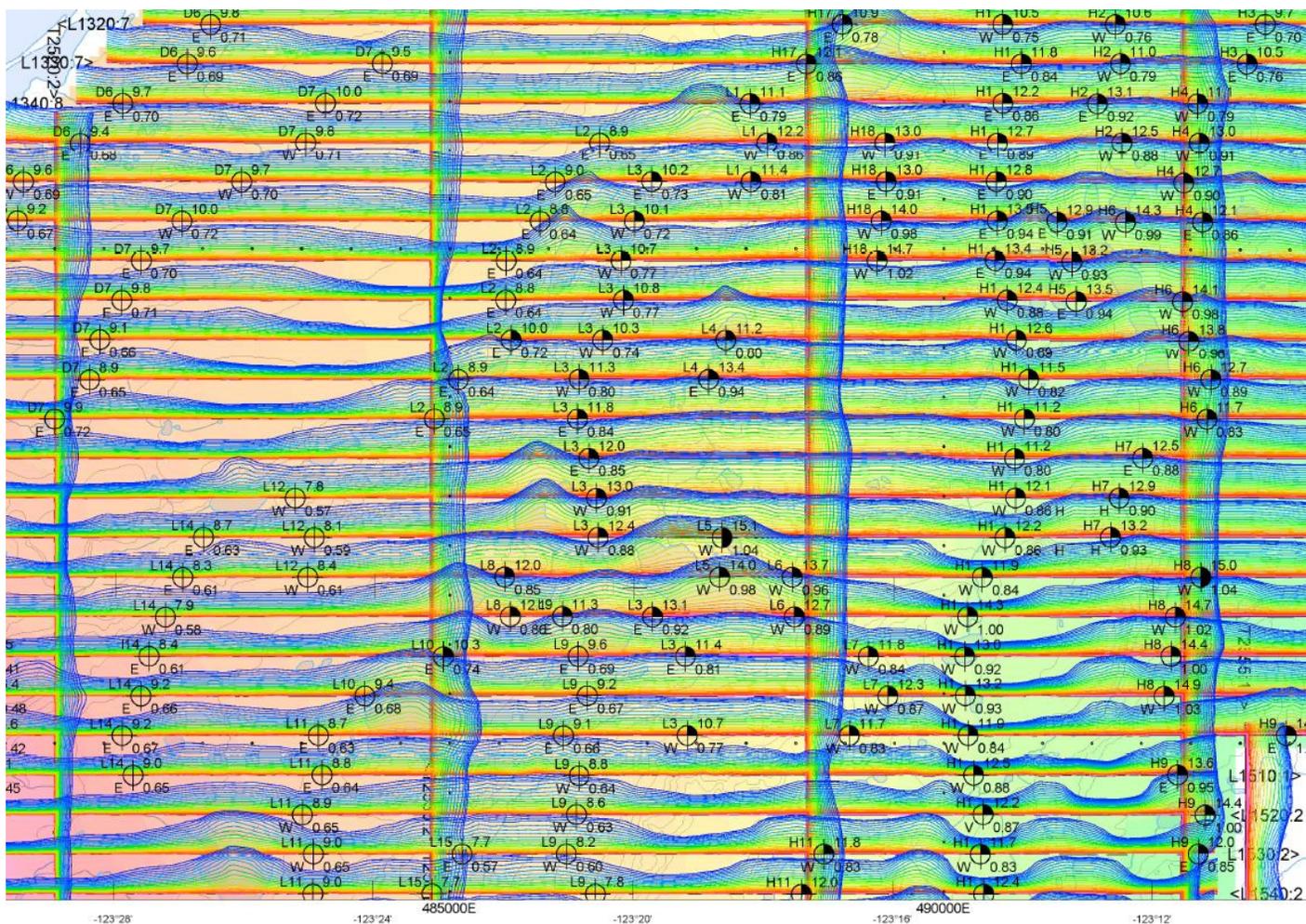
## Conductivity-Depth Image (CDI)



## TDEM B-field Z

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# Profile Map



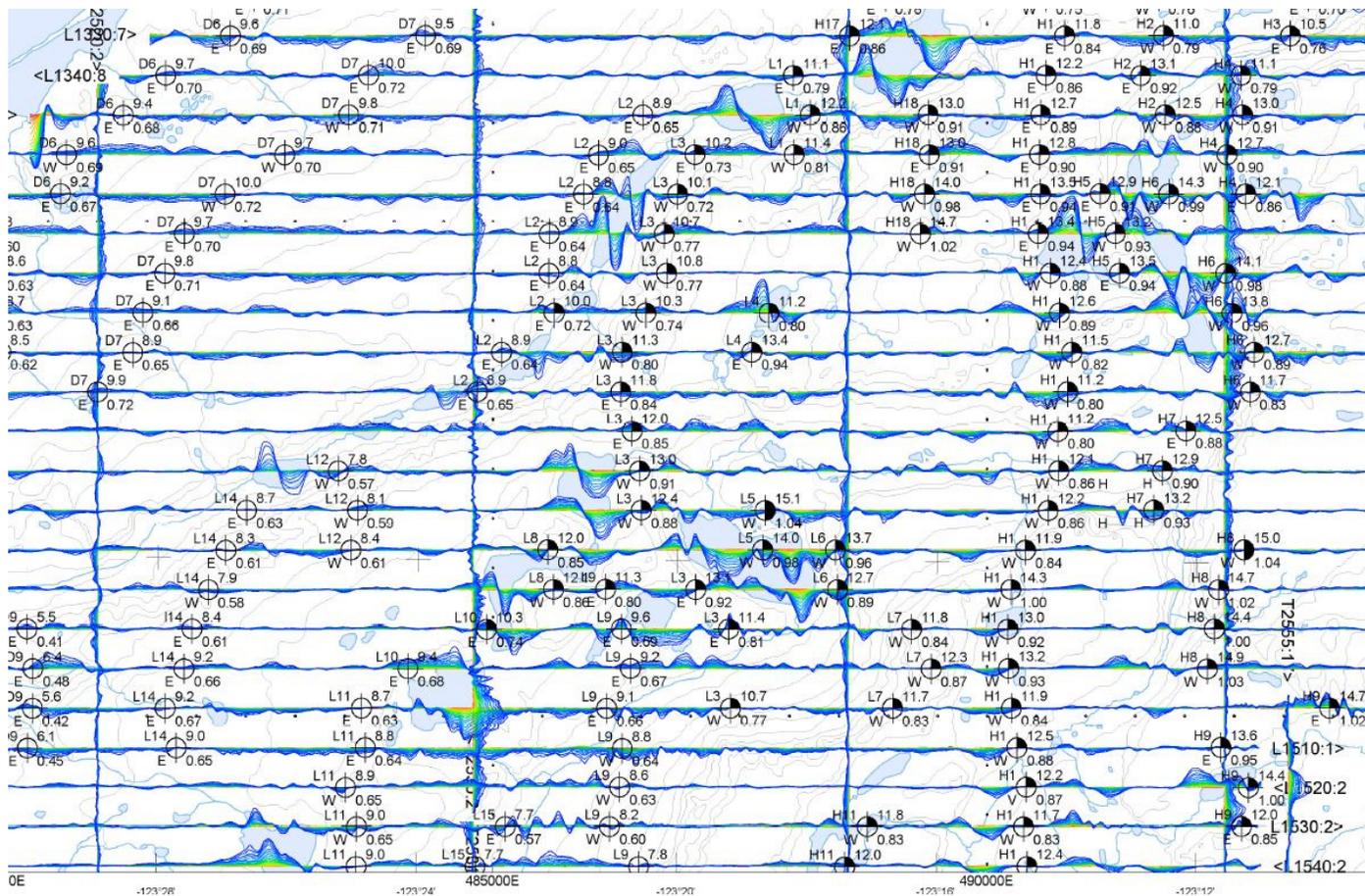
TDEM B-field Z with EM Anomalies



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# Profile Map



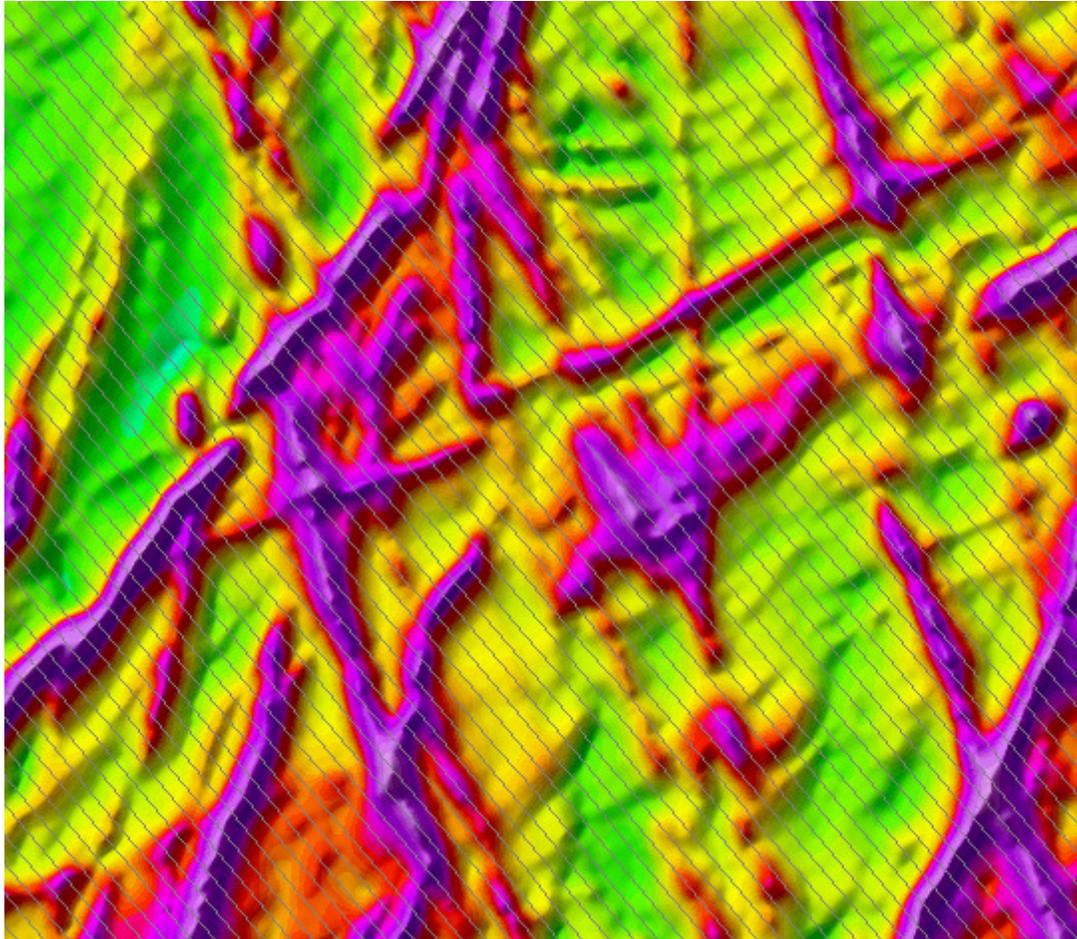
TDEM dB/dT X with EM Anomalies

# Gridding

- Interpolation of the data to provide a 2D representation for mapping and imaging
- Gridding is a form of filtering
- Data are aliased by high sampling rate along survey lines, and no sampling between survey lines
- Measured gradients, particularly the lateral horizontal gradient, can be used to improve interpolation of the total magnetic field
- Automatic or manual intervention can be incorporated to improve gridding of quasi-linear trends



# Gridding



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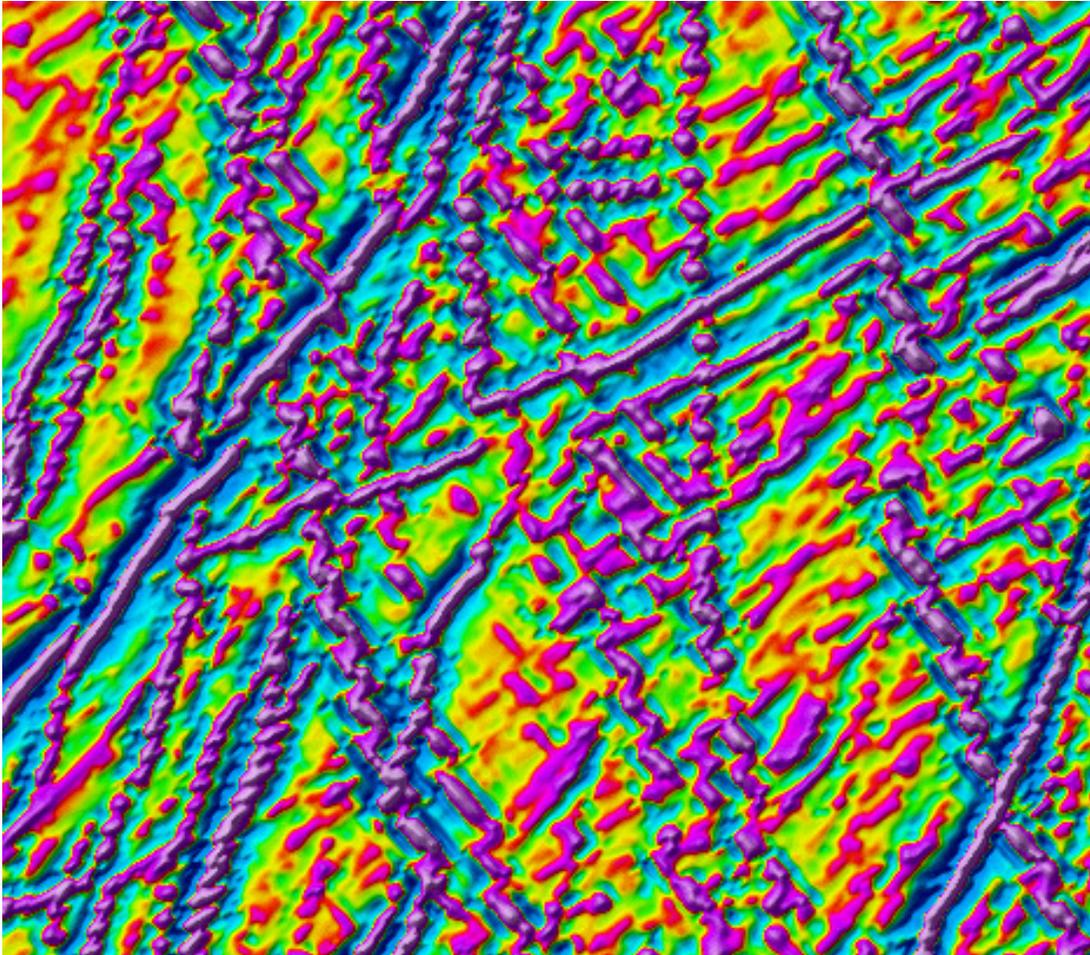
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# Gridding – Bi-directional



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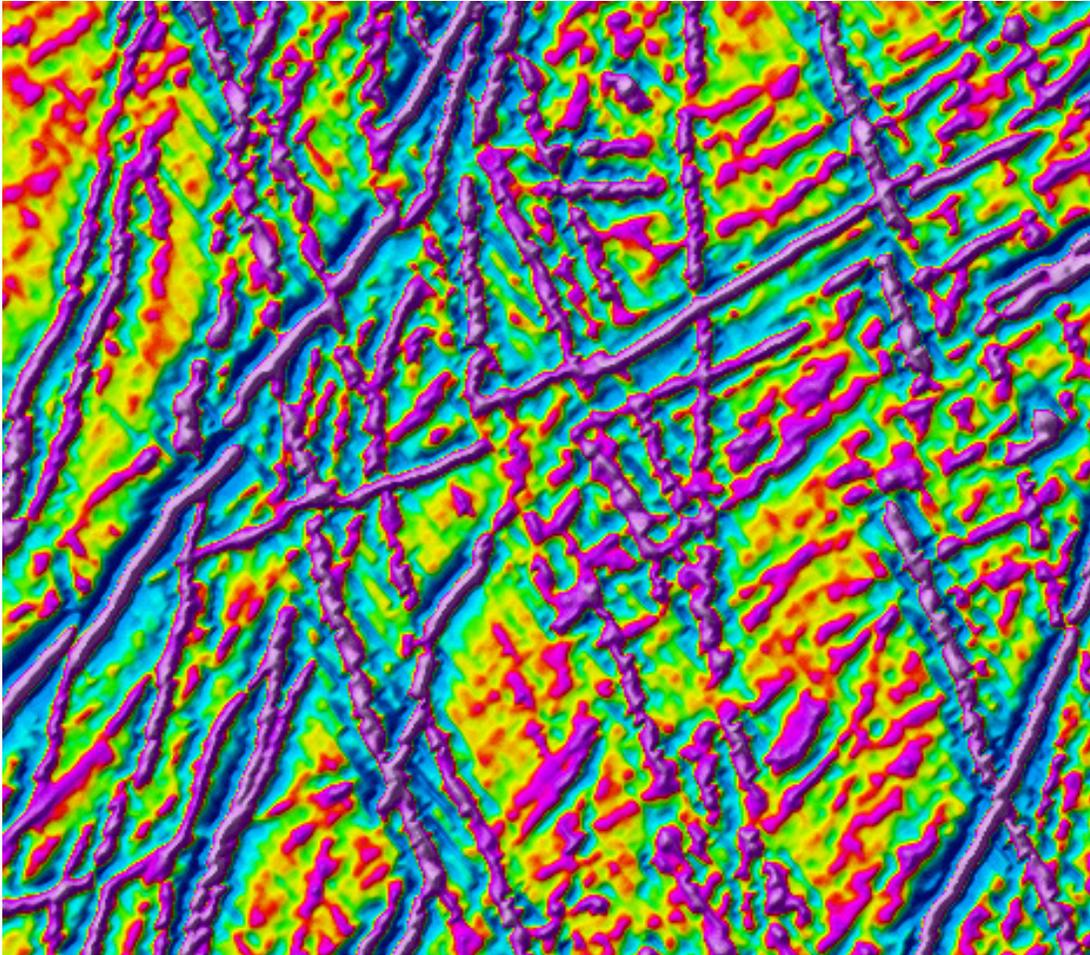
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# Gradient-enhanced Gridding – Bi-directional



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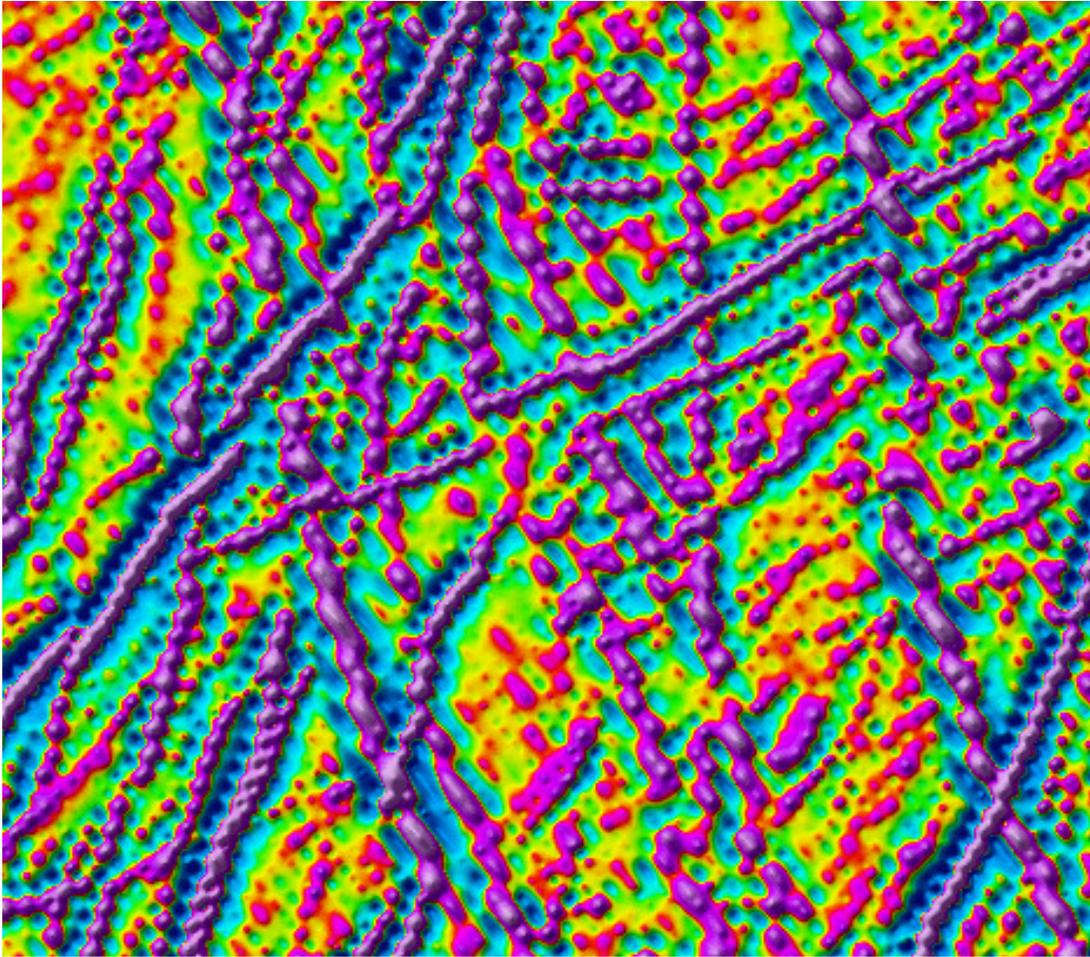
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# Gridding – Minimum Curvature



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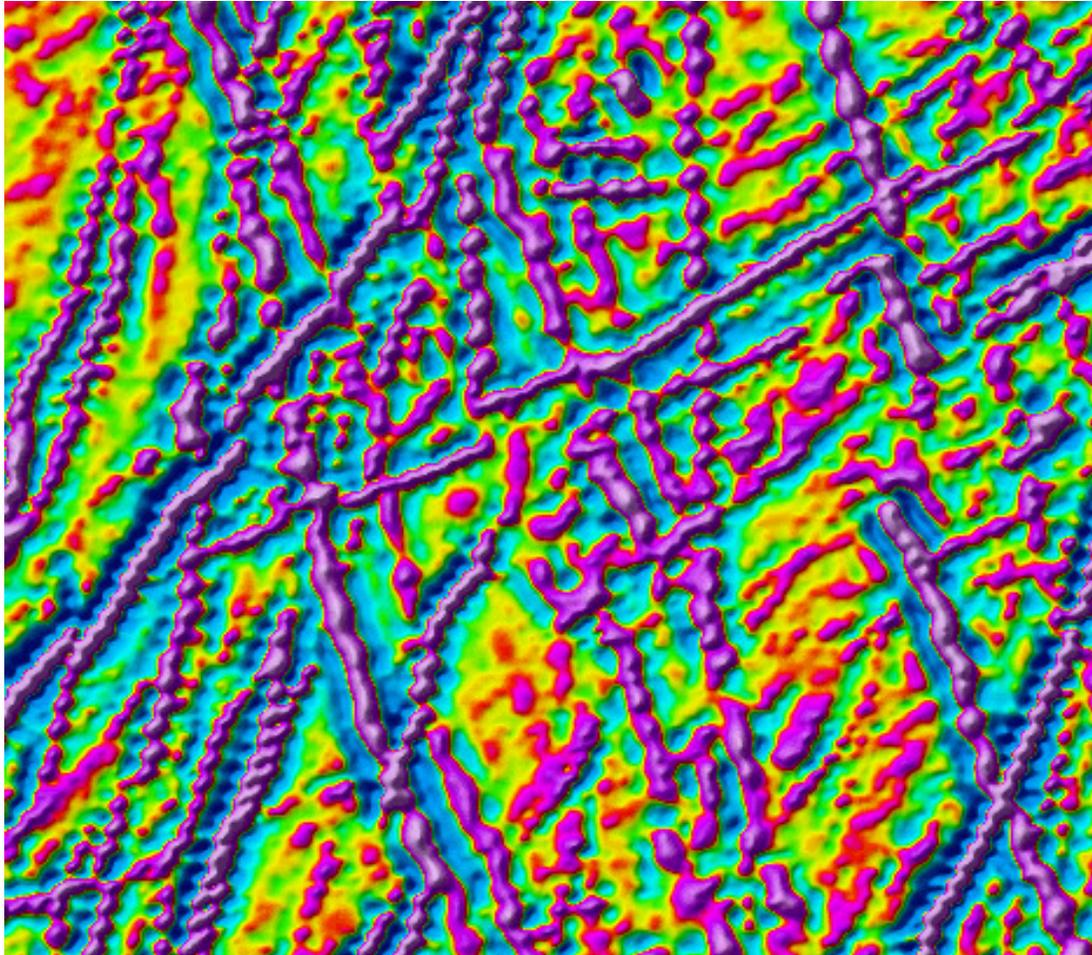
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# Gradient Enhanced Gridding – Minimum Curvature



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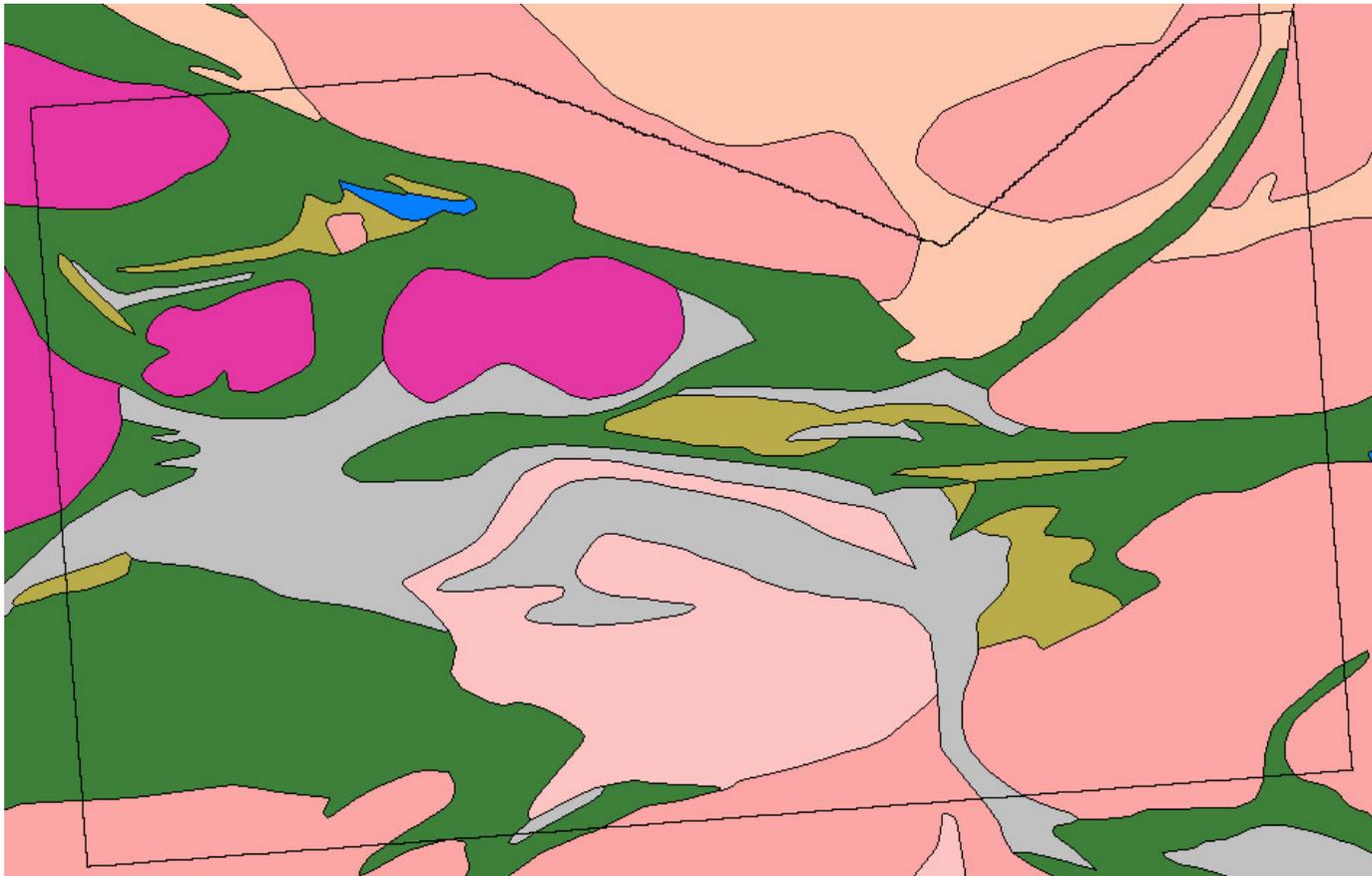
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# Imaging

- Imaging of data used to present the data in 2D form (e.g. prepare maps)
- Various imaging techniques to enhance certain components of the data (and suppress others)
- Powerful tool, particularly when combined with filtering

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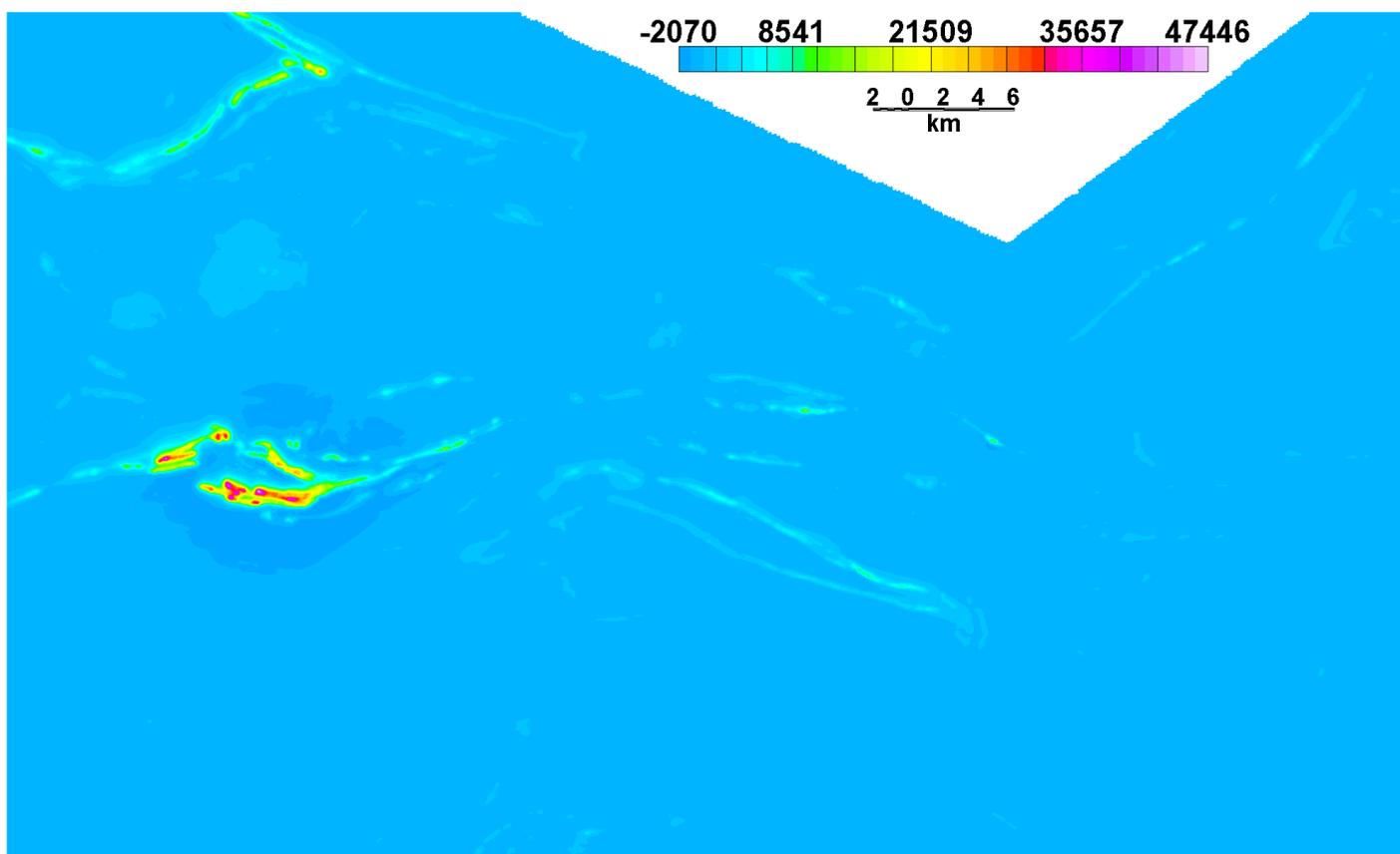
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# Colour Image – Linear Distribution



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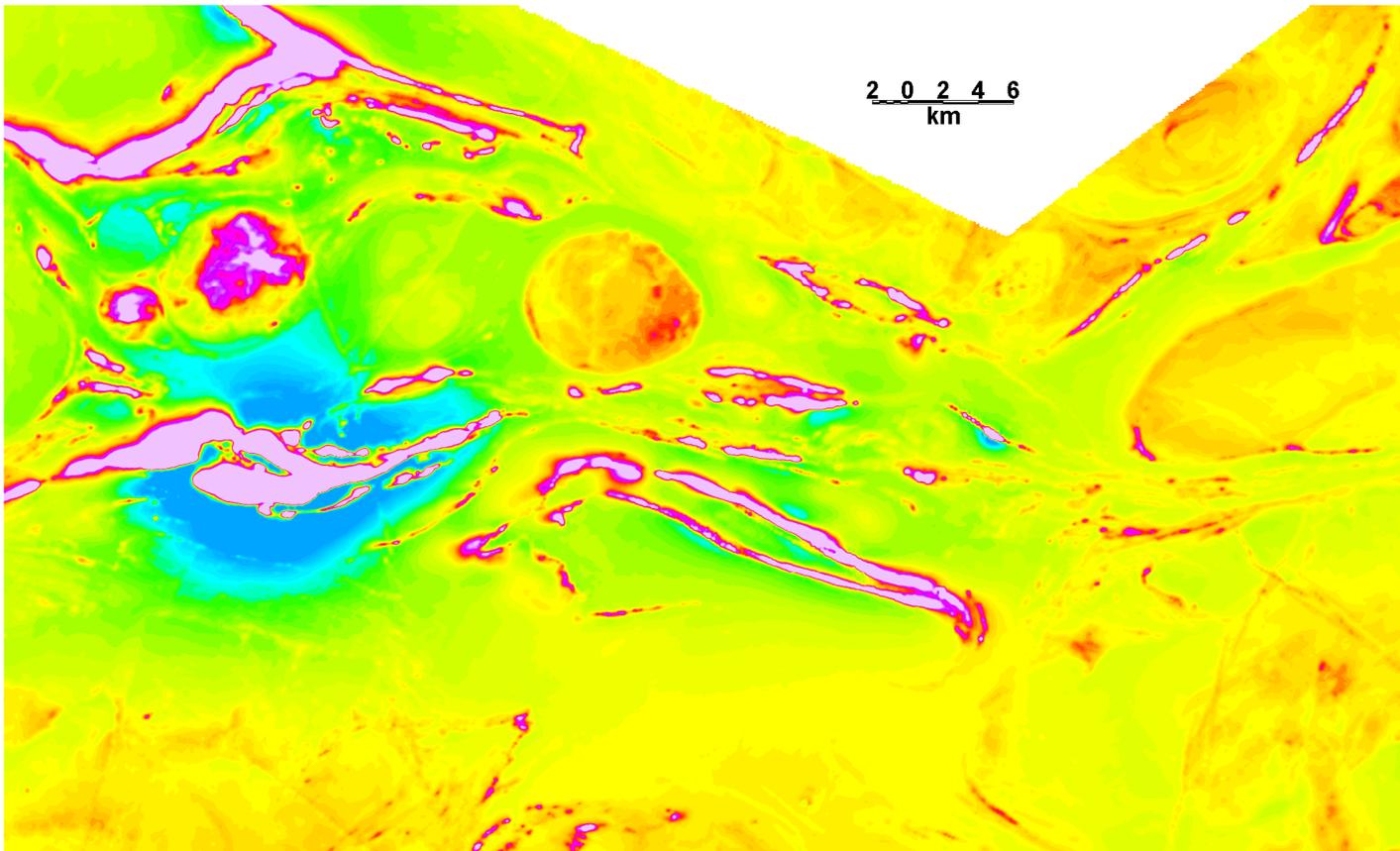
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# Colour Image – Adjusted Linear Distribution



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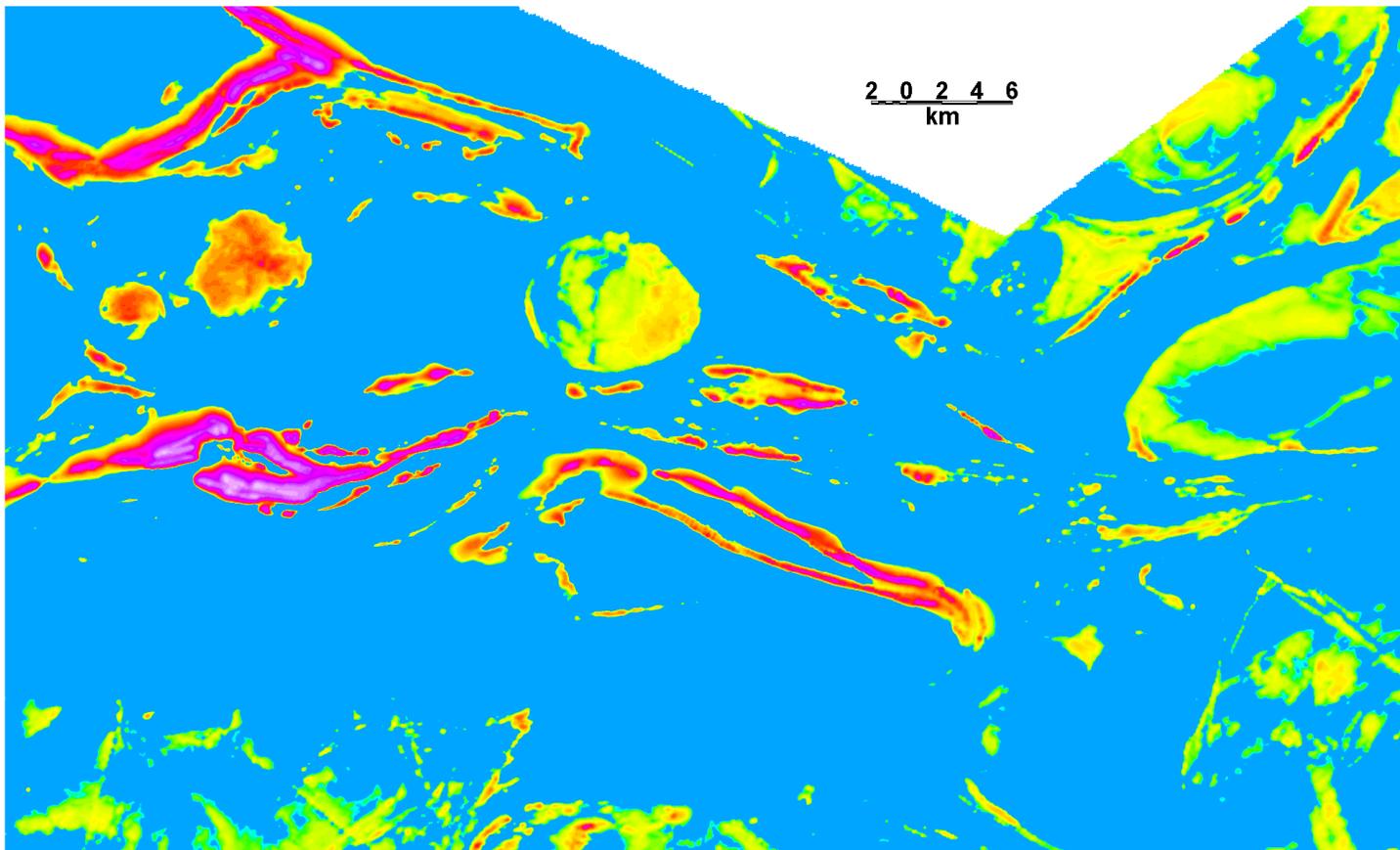
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# Colour Image – Log-Linear Distribution



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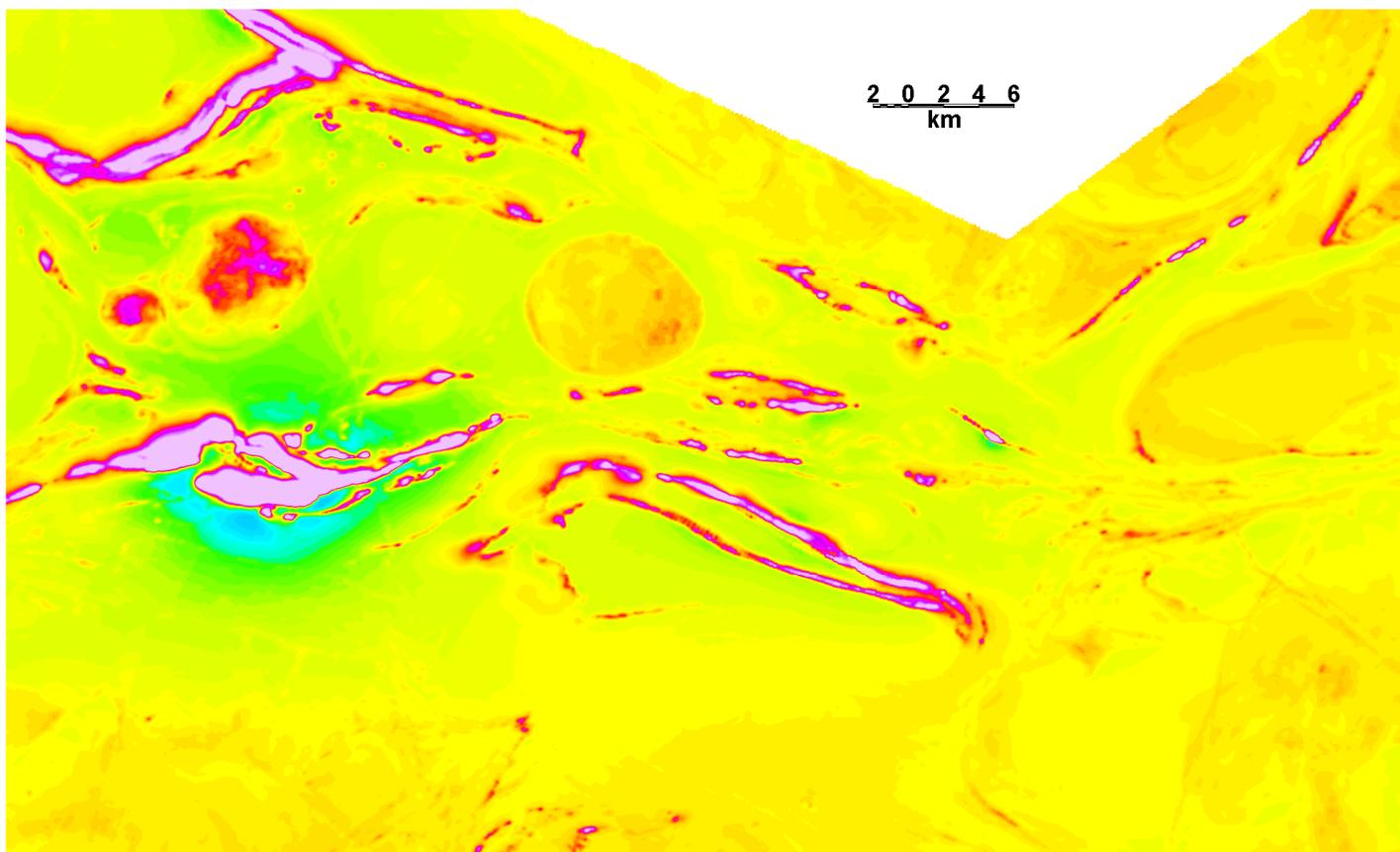
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# Colour Image – Normal Distribution



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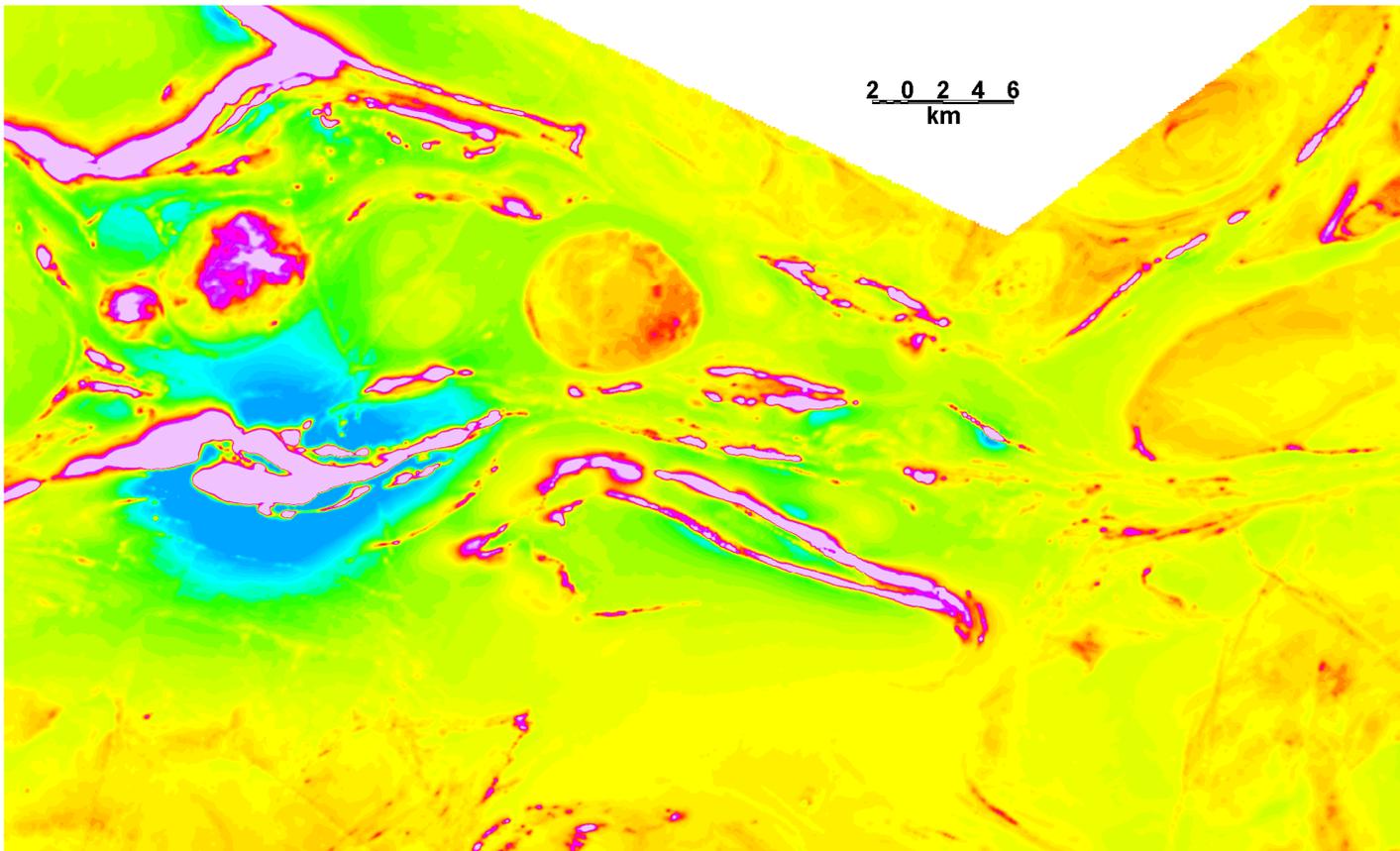
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# Colour Image – Adjusted Normal Distribution



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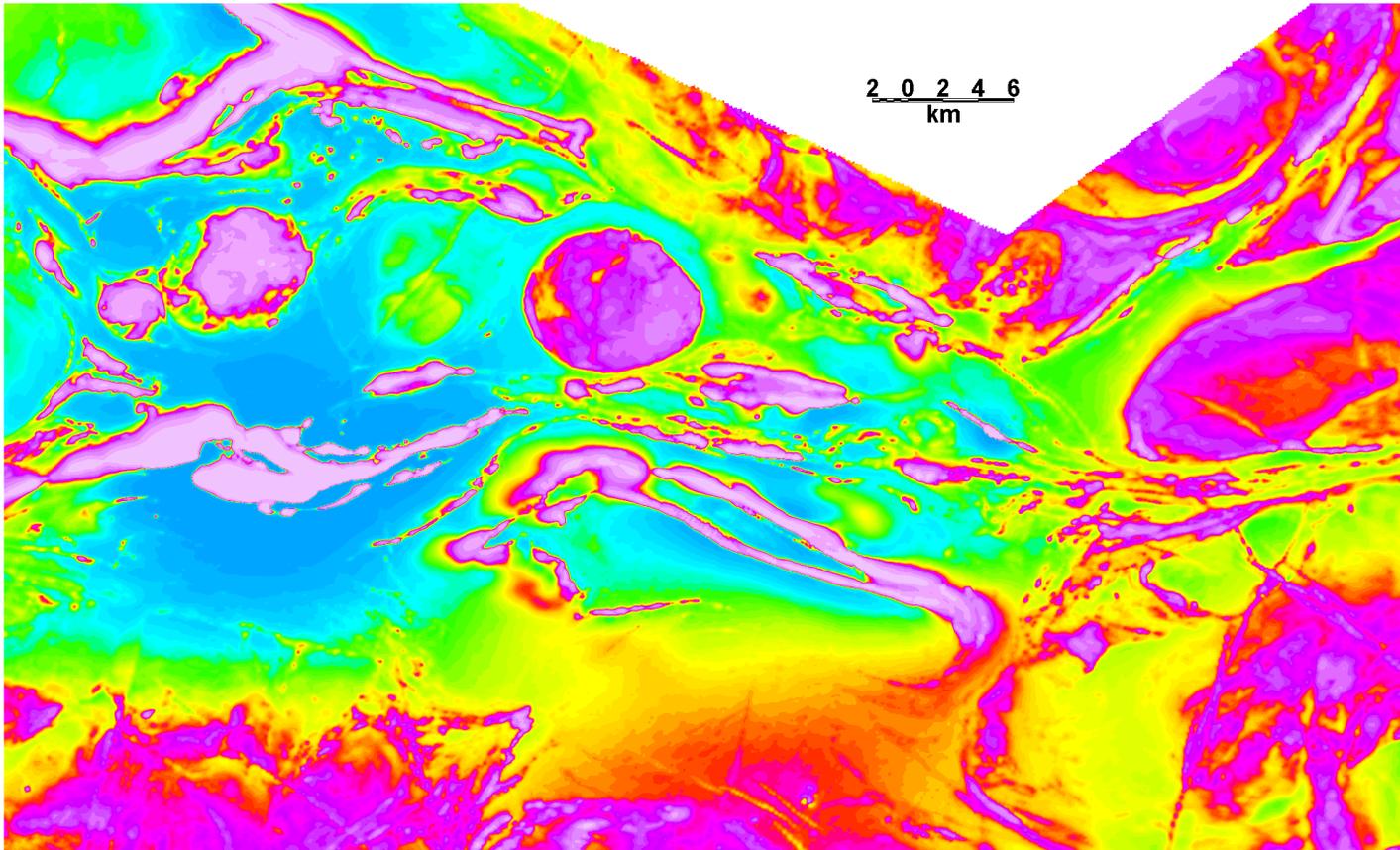
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# Colour Image – Equal Area Distribution



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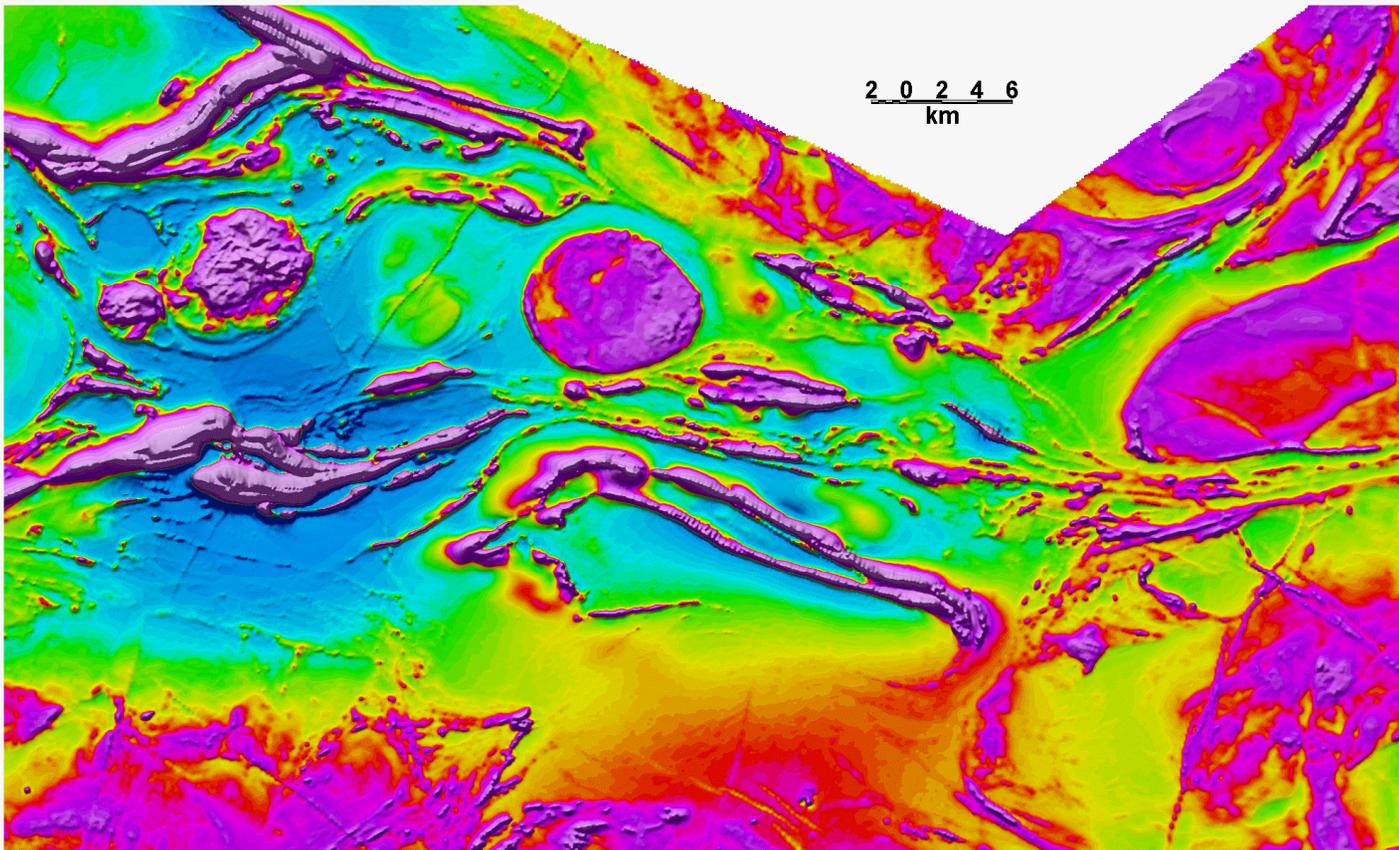
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# Shaded Colour Image – Equal Area Distribution



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# Grey-scale Image – Equal Area Distribution



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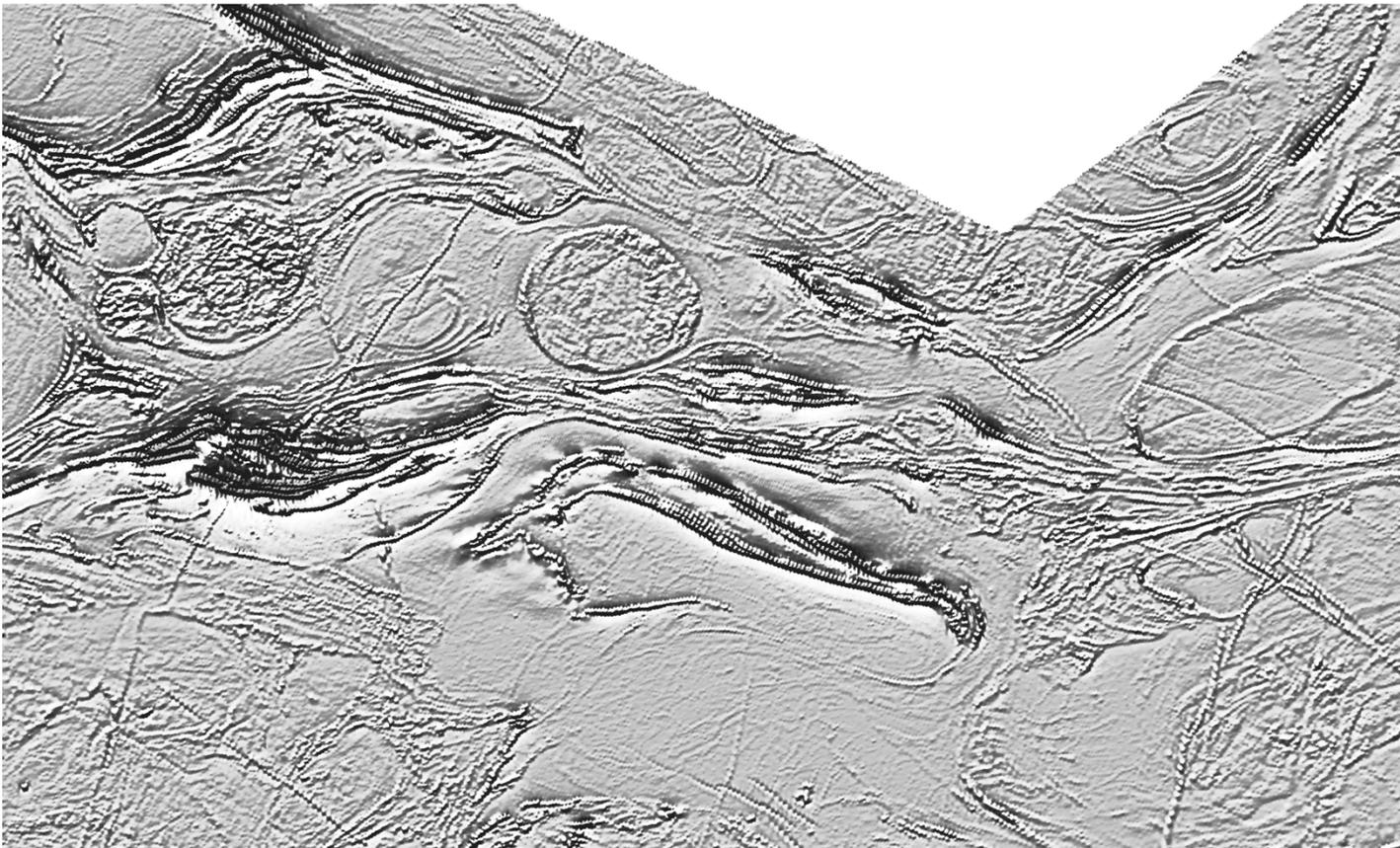
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# Shaded Relief Image – Equal Area Distribution



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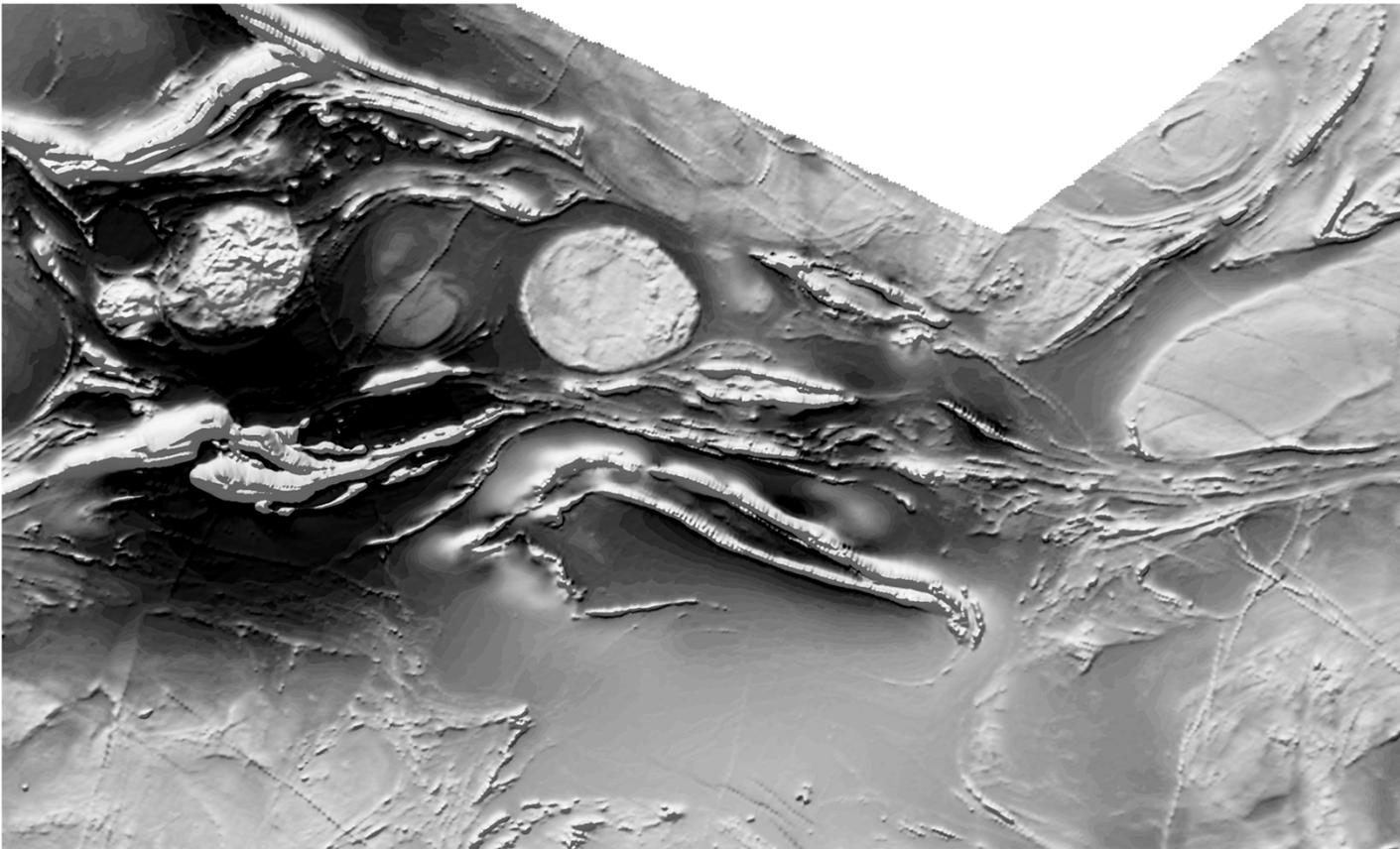
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# Shaded Grey-scale Image – Equal Area Distribution



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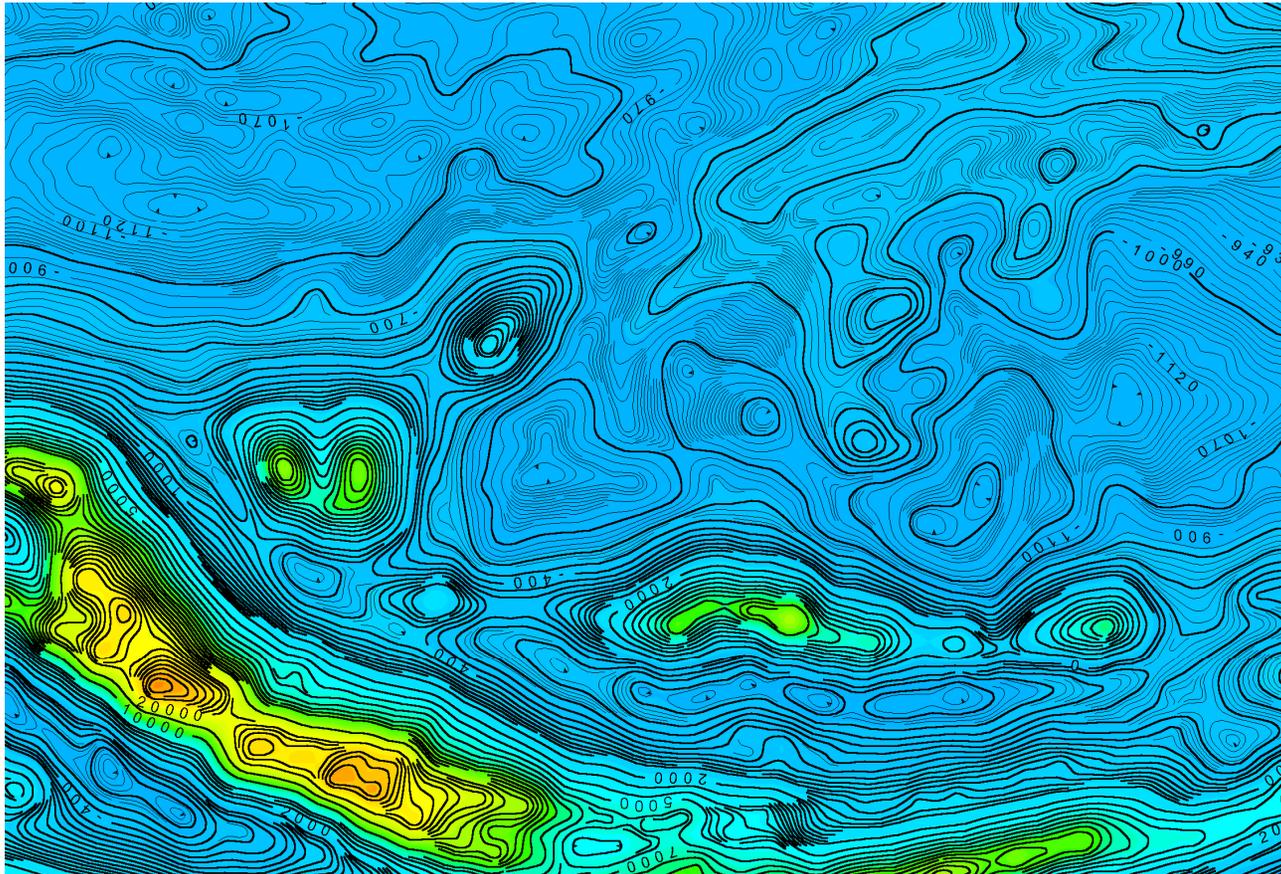
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# Colour-Contour Image – Linear Distribution



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# Filtering

- Filtering applied to enhance certain components of the data, suppress noise and/or to determine a physically meaningful result
- Most filters applied in the space-domain or frequency (Fourier)-domain
- Most filters have “physical meaning” but some are strictly for image enhancement
- Overly aggressive filtering can exaggerate noise or induce errors (e.g. ringing)

# Filtering

Formula	Measured	Filtered
$dF/dX$	Lateral Horizontal Gradient	Horizontal Derivative in X
$dF/dY$	Longitudinal Horizontal Gradient	Horizontal Derivative in Y
$dF/dZ$	Vertical Gradient	First Vertical Derivative

where F = magnetic or gravity field

- Numerous filters, transformations, depth estimation and modelling methods are dependent on the gradients
- High-frequency noise is amplified in the gradients if not properly corrected or removed

# Common Filters

Applicable to magnetic data, and also gravity data where indicated by a G

- Reduction to the Pole – removes the effect of the geomagnetic field inclination and declination – especially important at mid to low latitudes
- First and Second Vertical Derivatives (G) – preferentially enhances shorter wavelength anomalies, essentially due to nearer surface sources
- Horizontal derivatives (G) – preferentially enhances anomalies of a certain strike direction – similar to shaded relief

# Common Filters

- Total Horizontal Derivative (G) – emphasizes source edges (contacts) – TDX filter does a better job for automated edge detection but is less intuitive for interpretation
- Analytic Signal Amplitude – simplifies magnetic anomalies by locating magnetic source edges regardless of geomagnetic field and magnetic remanence
- Tilt Angle (G) – minimizes variations in anomaly amplitude to enhance subtle features – also called tilt derivative

# Common Filters

- Low Pass (G) – many variations e.g. regional field
- High Pass (G) – many variations e.g. residual field
- Band Pass (G) – to focus on sources at intermediate wavelengths e.g. spectral slicing (correlates with depth)
- Upward/Downward Continuation (G) – simulate field at higher or lower elevations
- Directional (G) – to pass or reject signal in a certain direction e.g. dykes, level noise (microlevelling)
- Apparent Magnetic Susceptibility – estimation of physical property (can also be computed from FDEM data)
- Pseudo Gravity – transforms magnetic field for comparison to the gravity field



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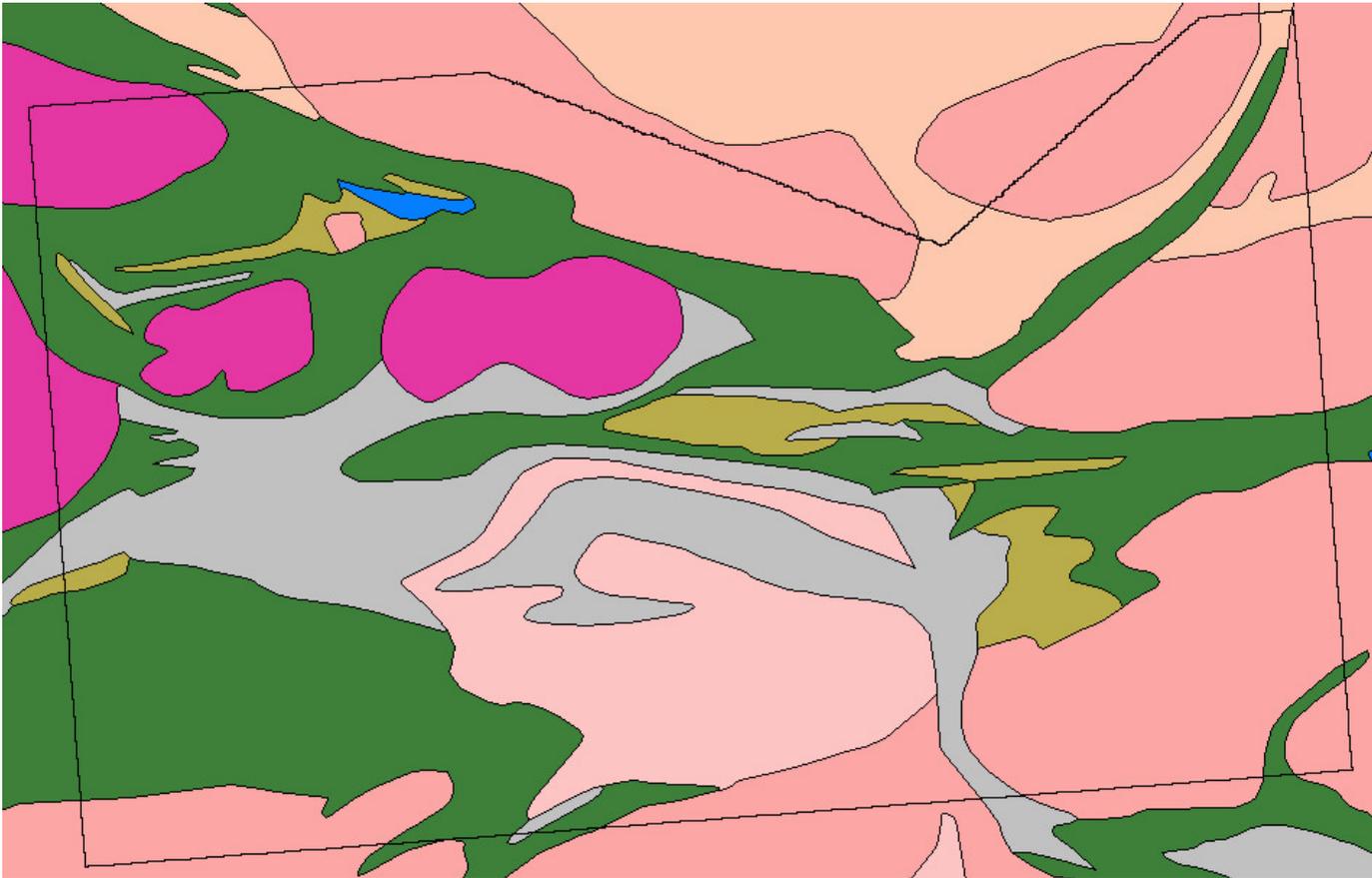
# Other Filters and Transforms

- Apparent Density – estimation of physical property from gravity data
- Isostatic Residual – removes isostasy effects from gravity data
- Ternary Radiometric Image – RGB image of K, Th and U to display variation and intensity of radioelements
- Radioelement Ratios – Th/K, U/K and U/Th useful for detailed lithologic mapping and locating alteration

# Other Filters and Transforms

- Decay Constant – useful for characterizing TDEM conductors
- Apparent Resistivity/Conductivity/Conductance – maps halfspace or layered earth model from TDEM and FDEM data
- Conductivity Depth Imaging – conductivity section along flightlines that can then be viewed in plan or 3D

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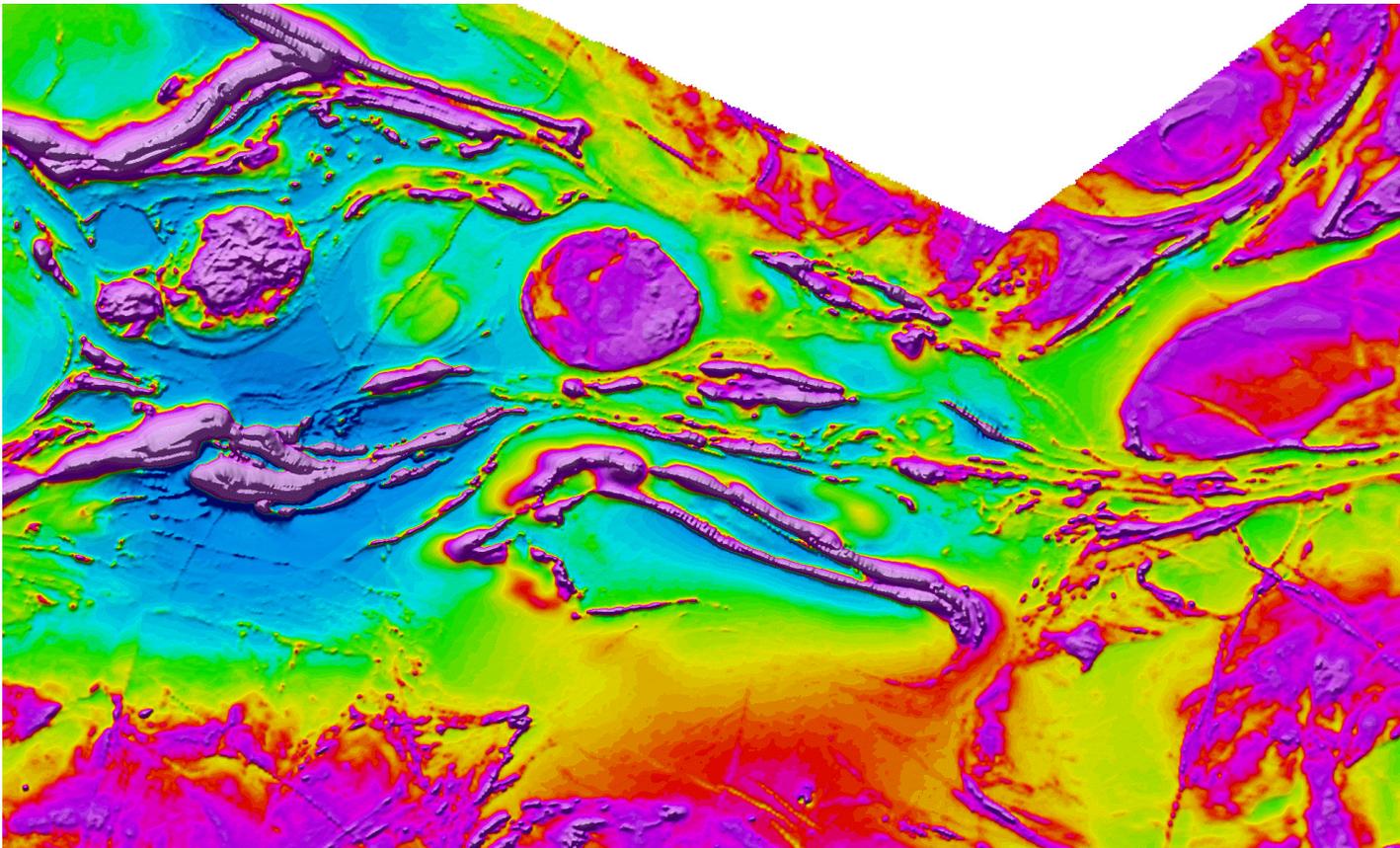
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# Total Magnetic Field



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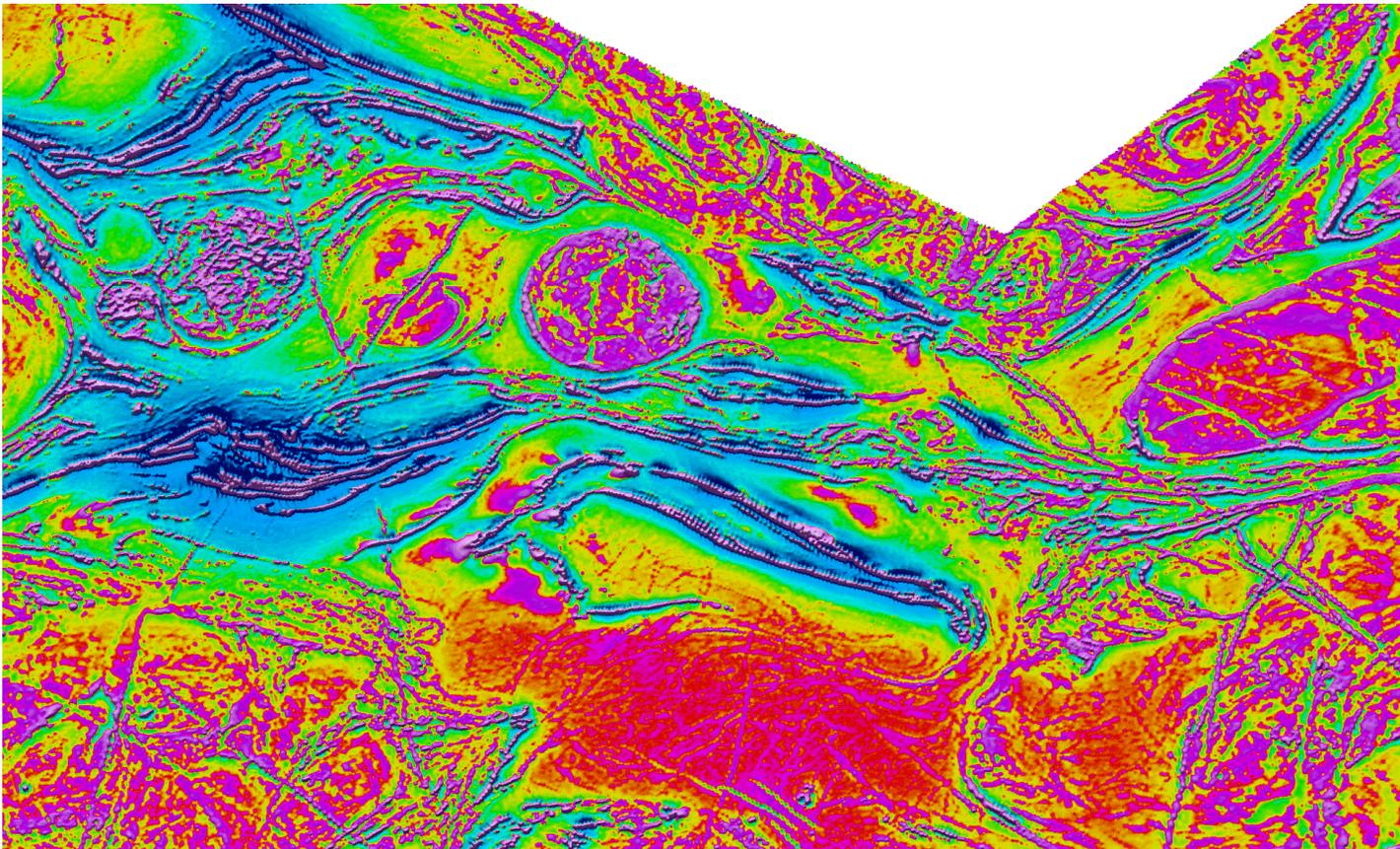
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# First Vertical Derivative



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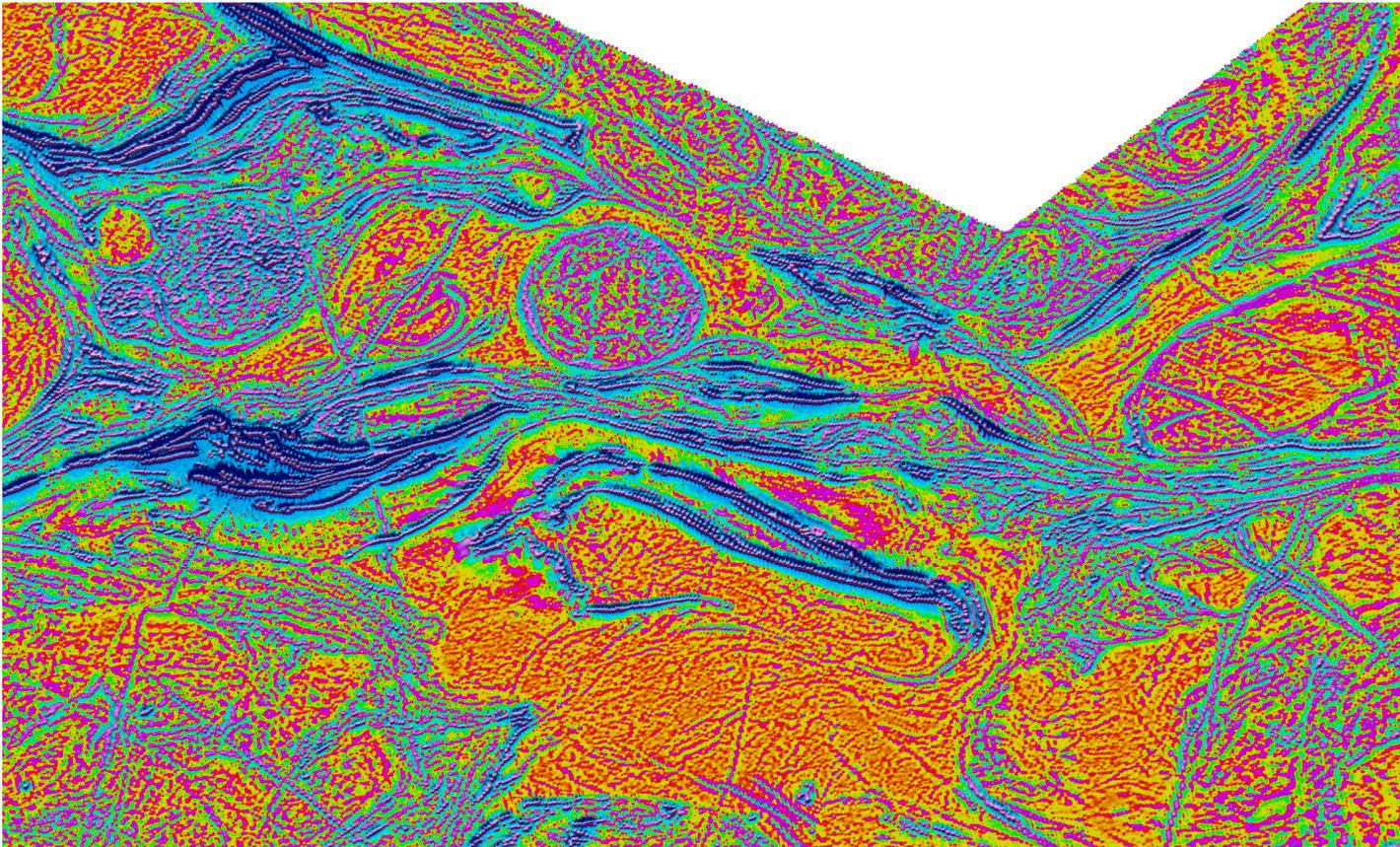
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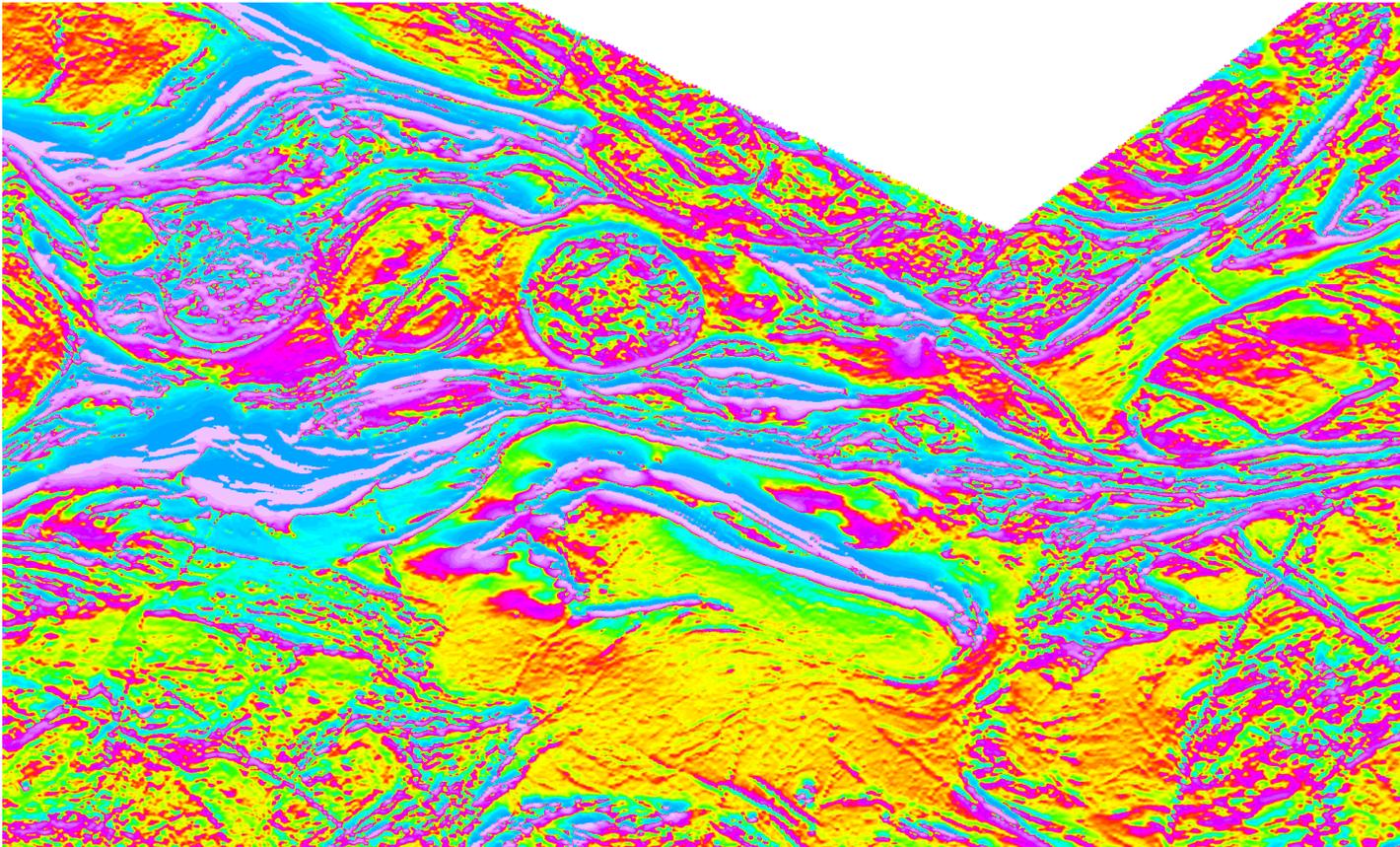
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# Second Vertical Derivative



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# Horizontal Derivative in Y-direction



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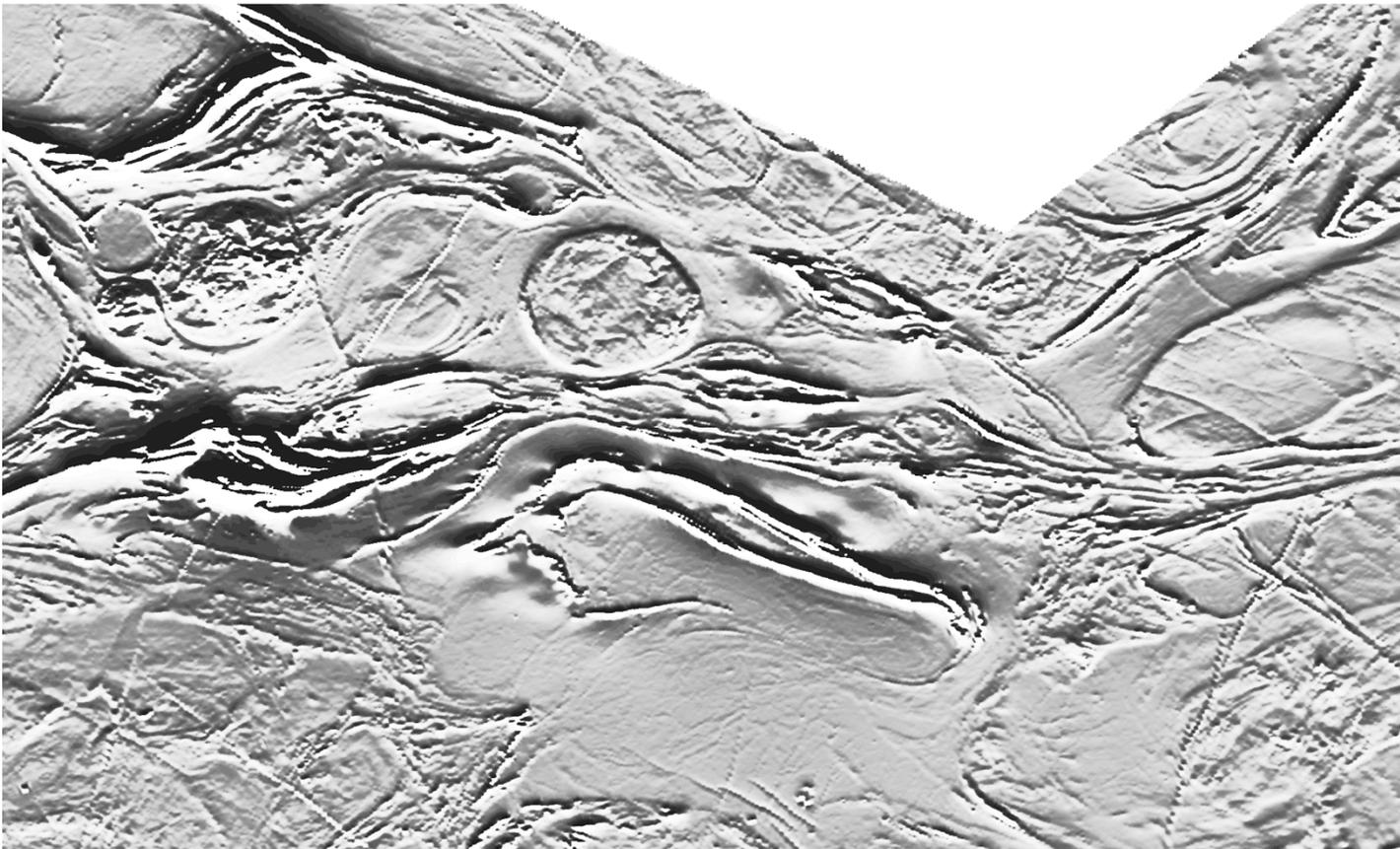
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# Horizontal Derivative in Y-direction



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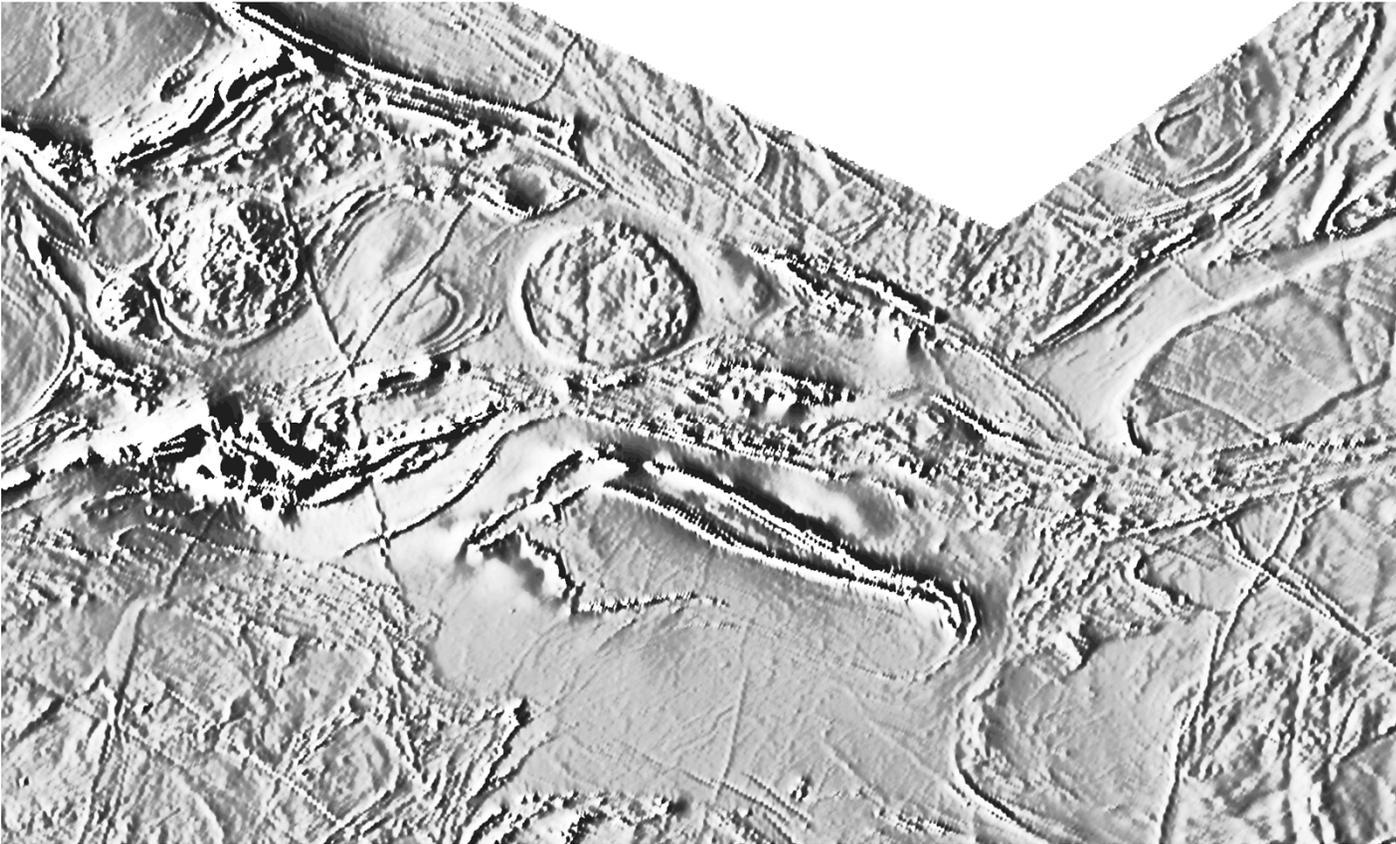
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# Horizontal Derivative in X-direction



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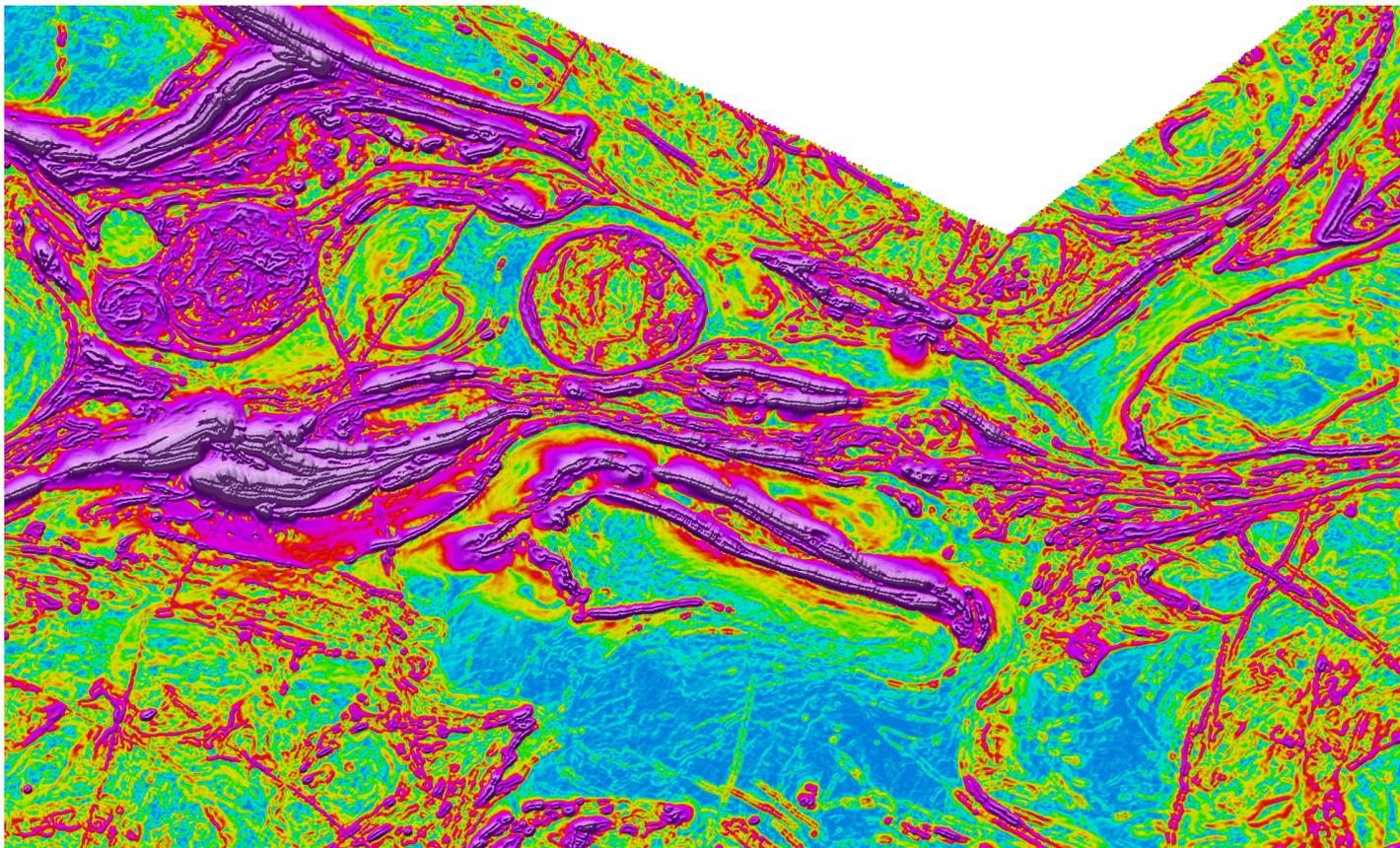
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# Total Horizontal Derivative



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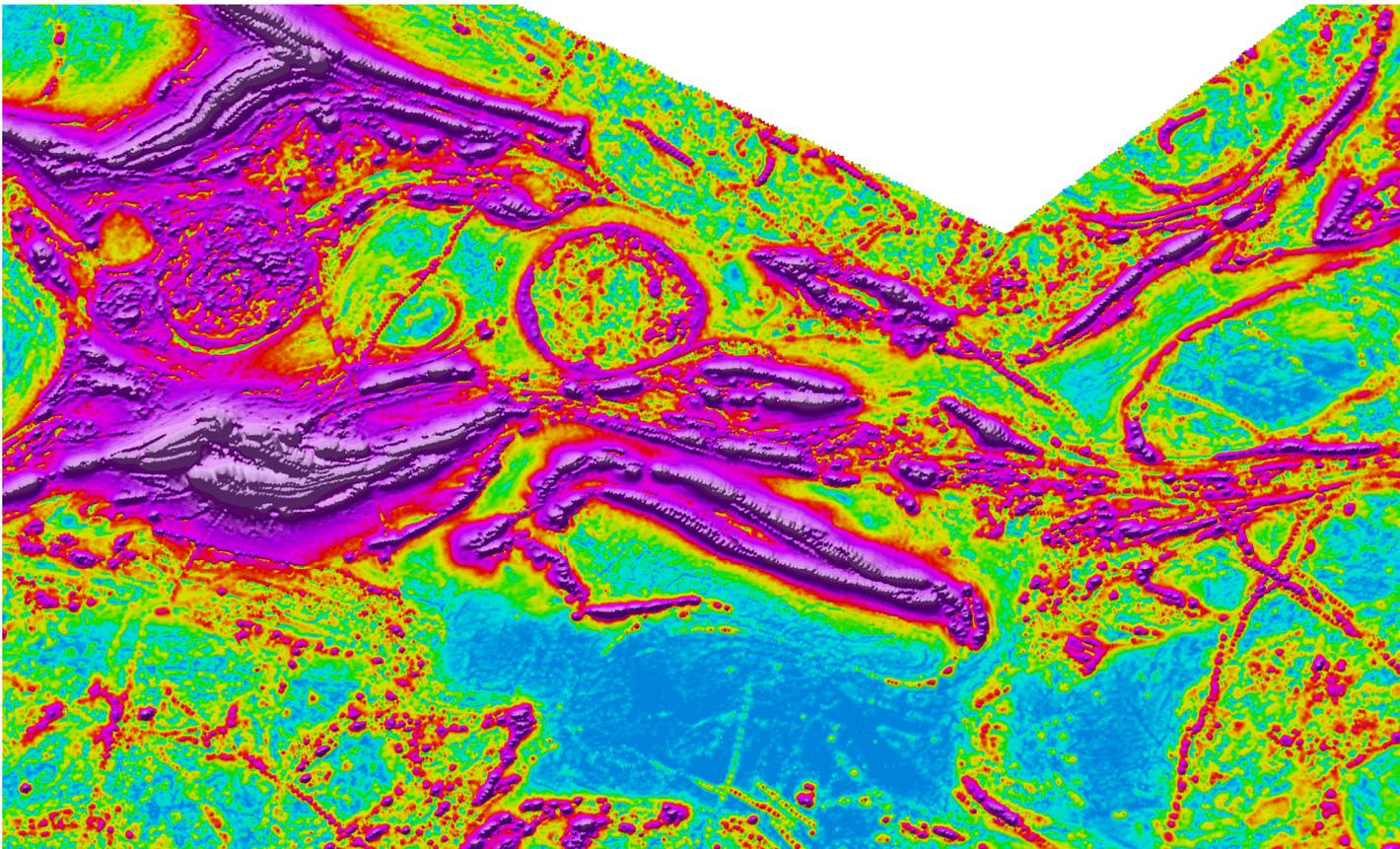
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# Analytic Signal Amplitude

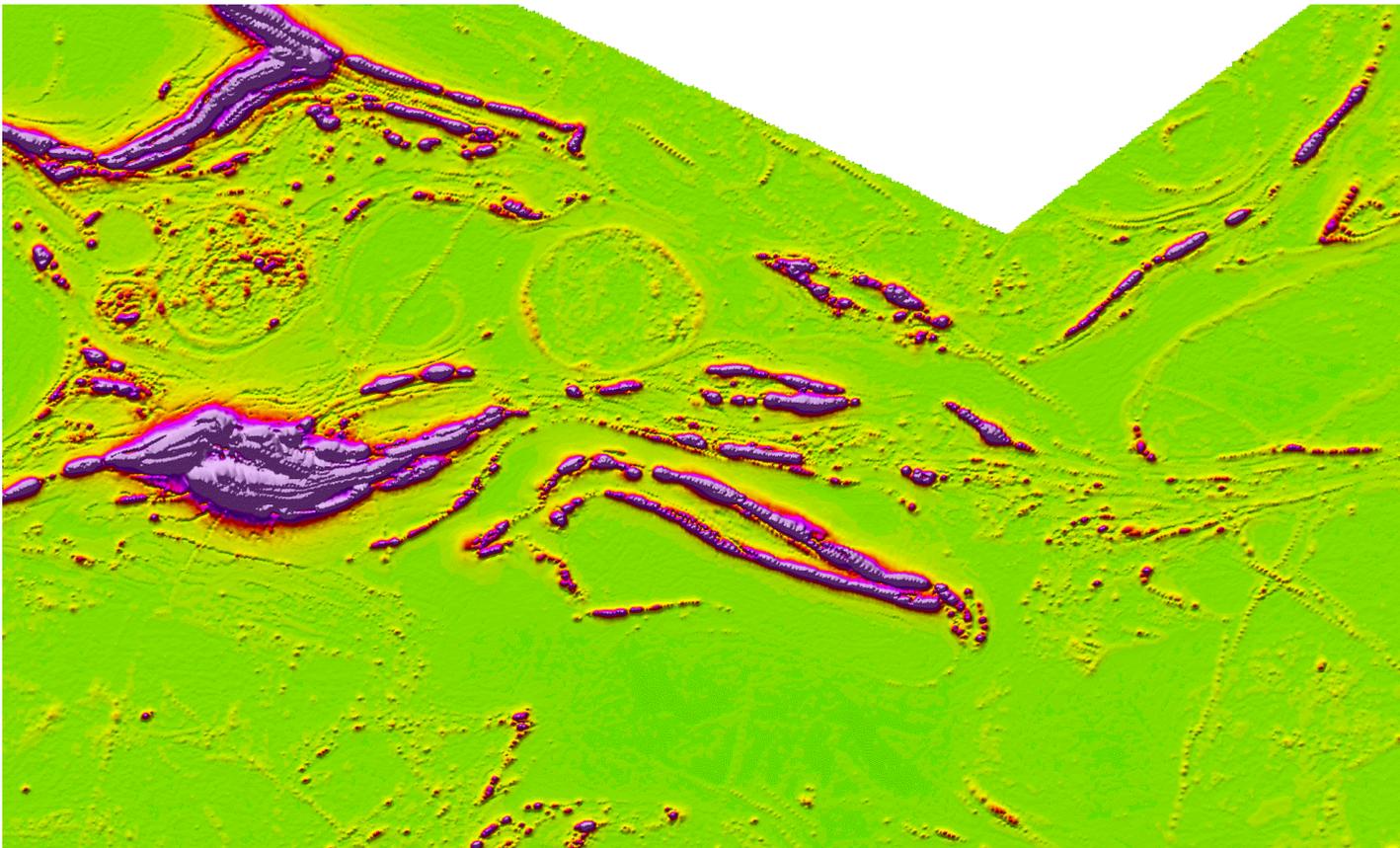
Equal area distribution



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# Analytic Signal Amplitude

Normal distribution



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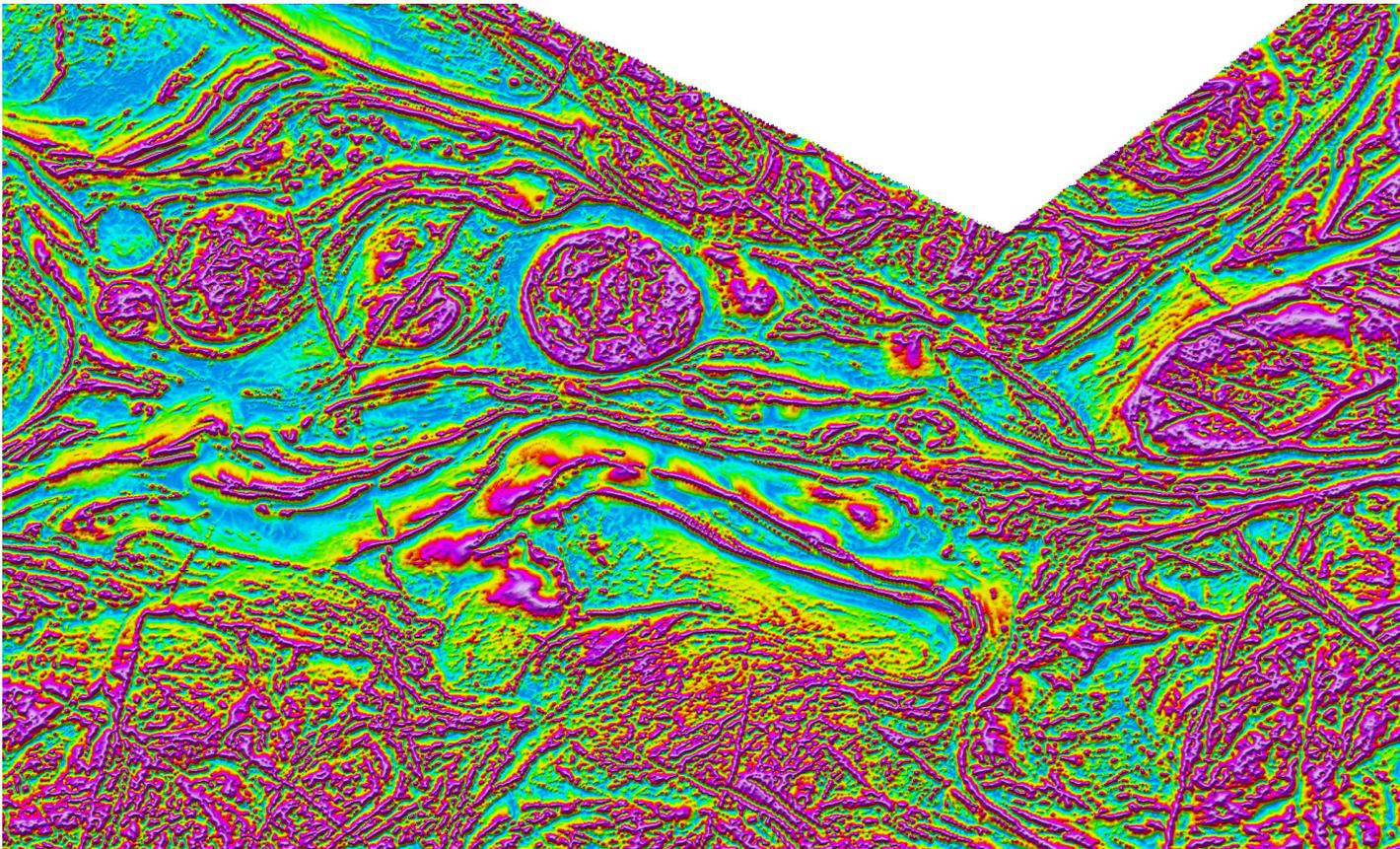
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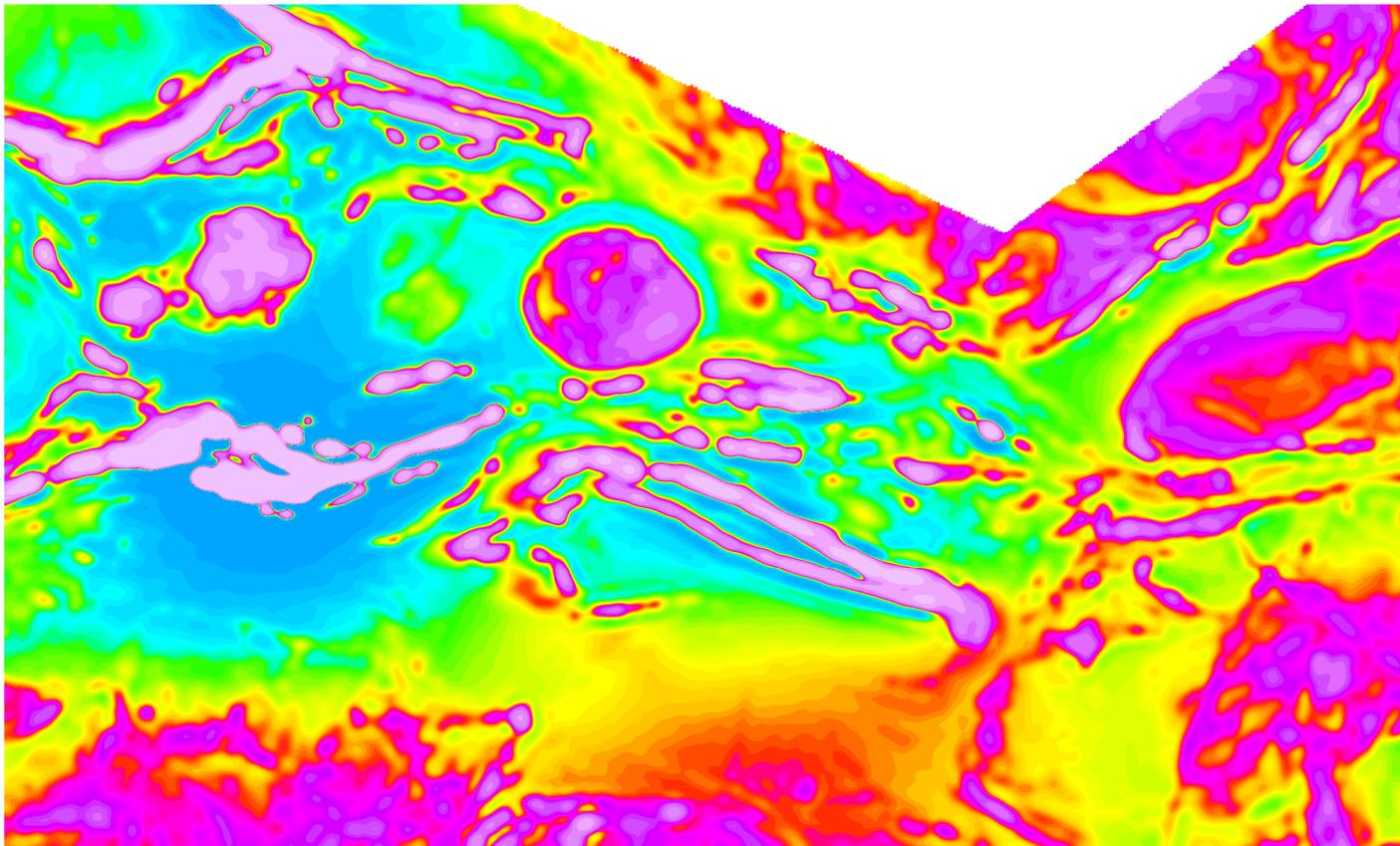
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# Tilt Derivative



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# Regional Magnetic Field



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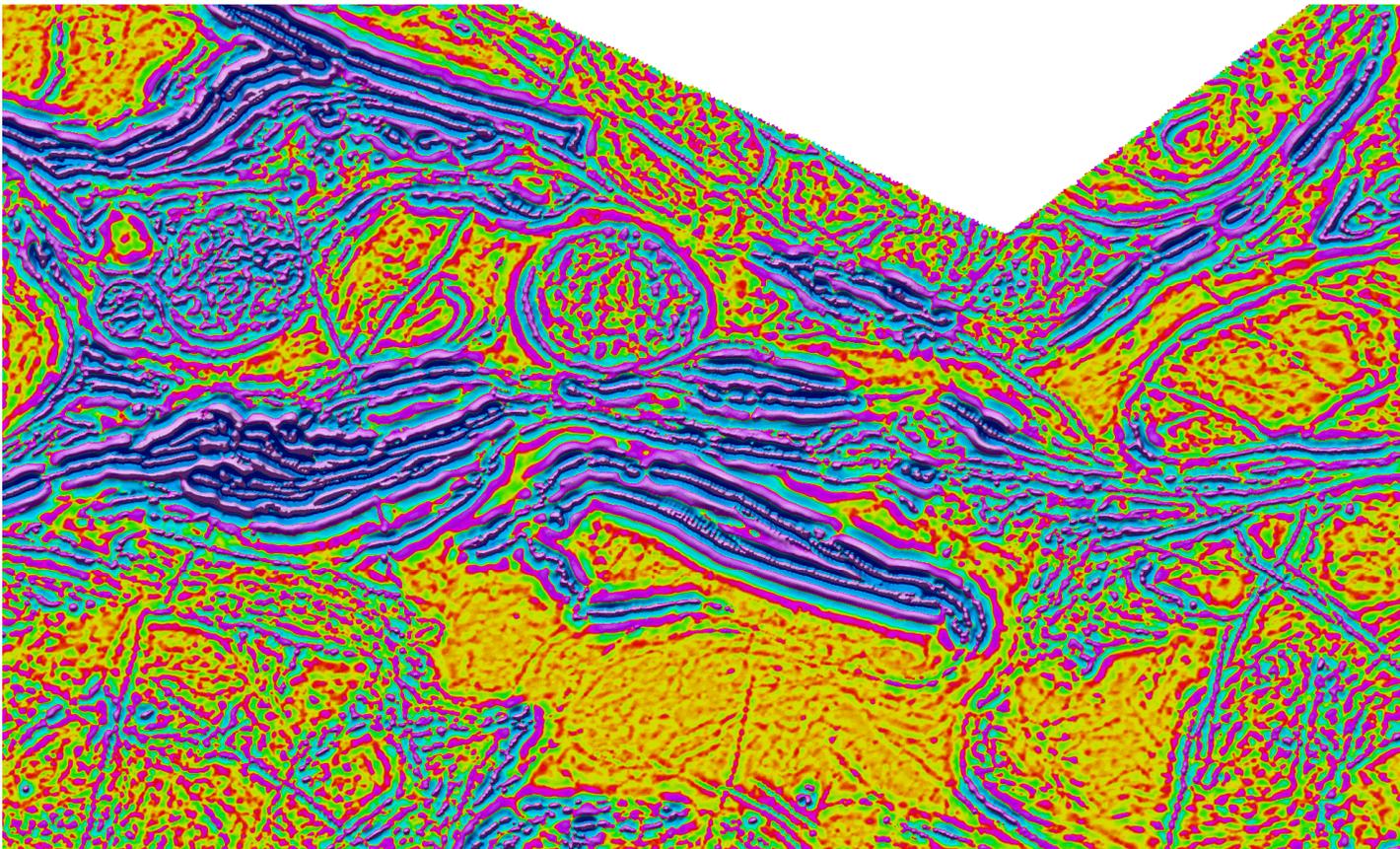
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# Residual Magnetic Field



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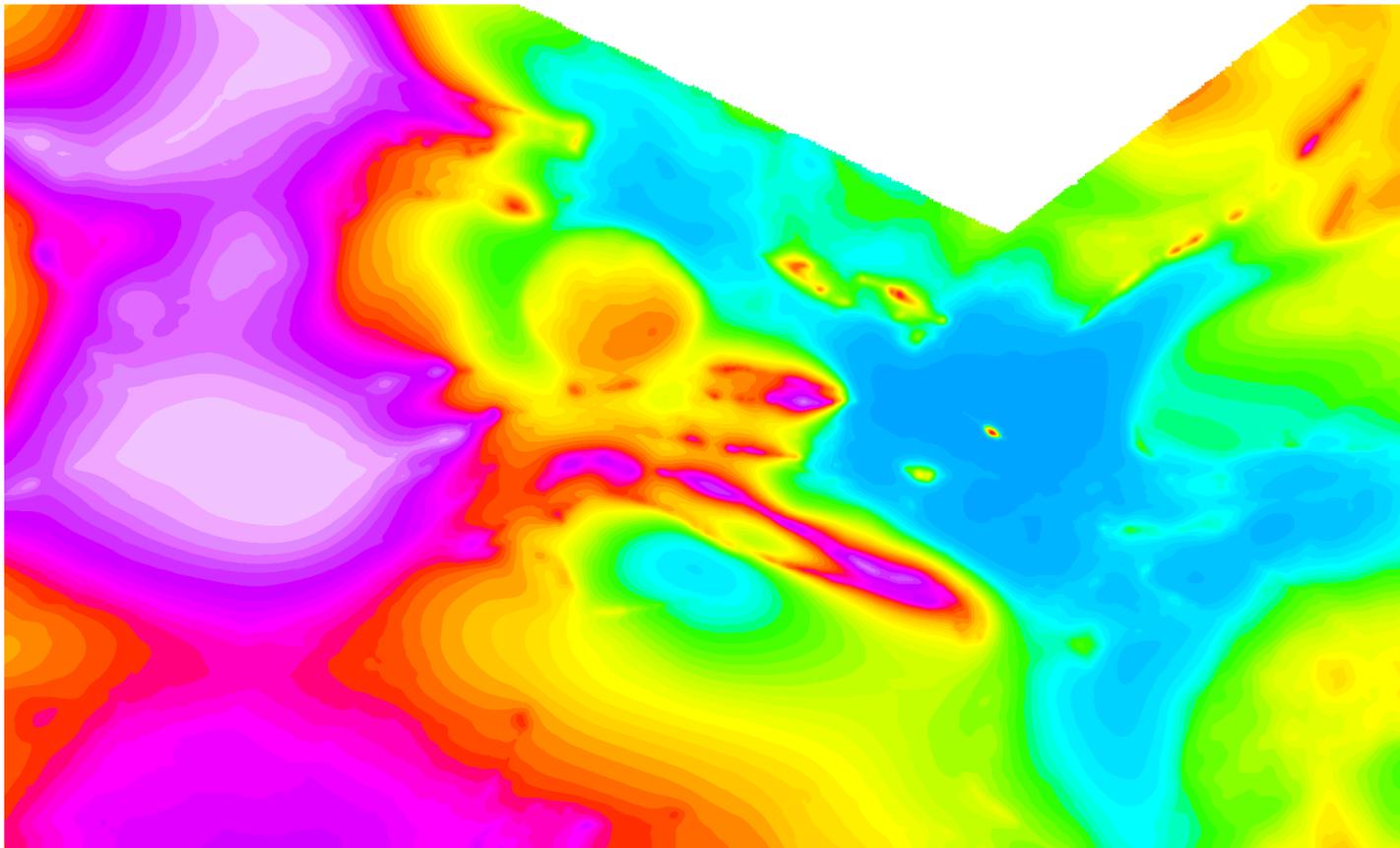
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# Pseudo Gravity Field



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# Gradient/Grid-based Methods

- Detection of edges to map contacts
  - Apply grid transformation (total horizontal derivative or TDX) to peak over edges
  - Extract edges over peaks and join into continuous lineaments (CET)
- Detection of peaks and troughs to map quasi-linear features e.g. dykes, foliation, magnetic stratigraphy

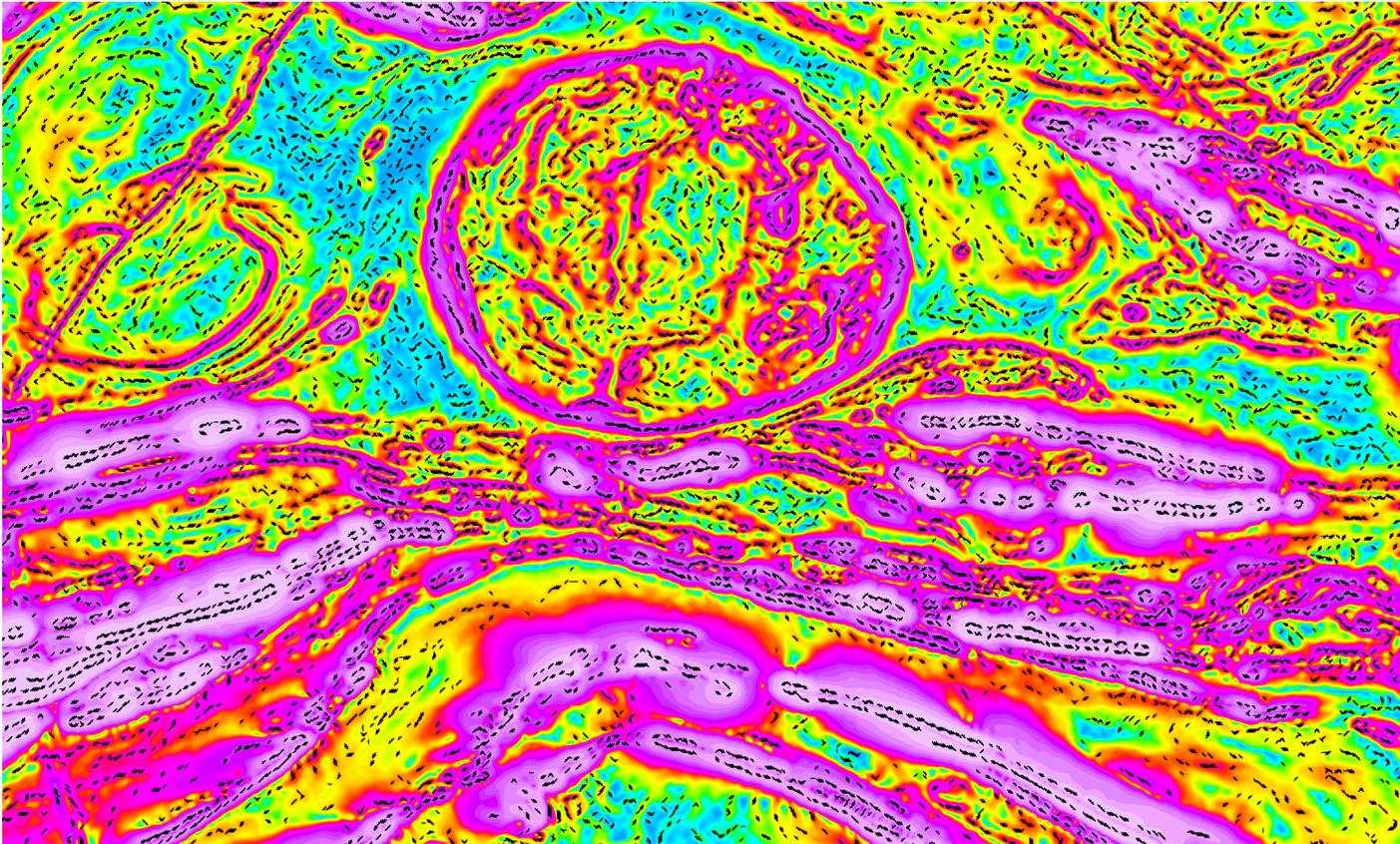
# Gradient/Grid-based Methods

- Extract edges at various continuation levels (multi-scale worms) to assess location and dip of deep-seated structures
- Location and depth of magnetic sources using line and grid-based methods e.g. source-parameter imaging<sup>TM</sup>, Euler deconvolution, Naudy, analytic signal, Werner deconvolution
  - Assumes a geometric model



# Source-edge Detection

Over total horizontal derivative (peaks)



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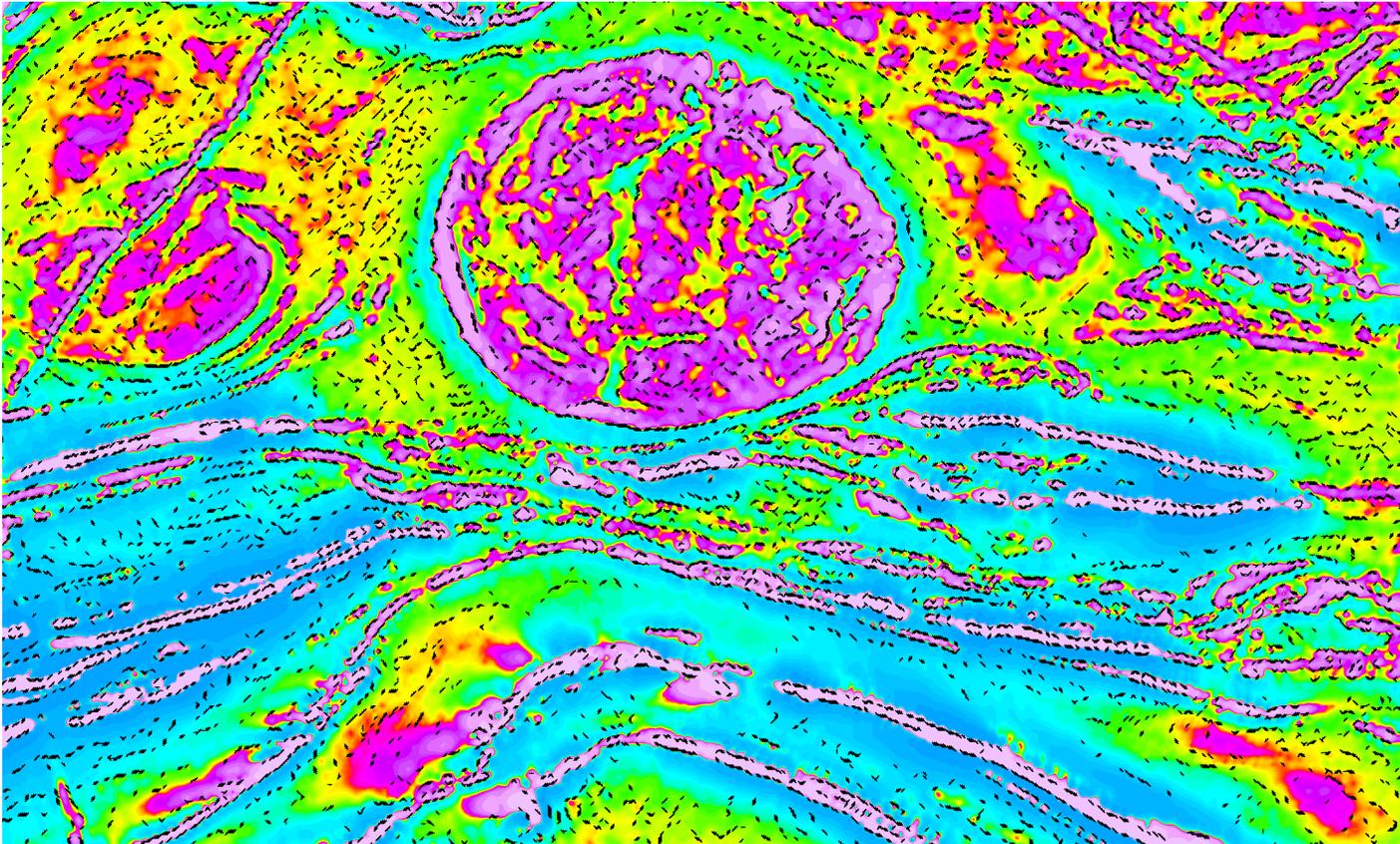


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# Source-edge Detection

Over first vertical derivative (contacts)



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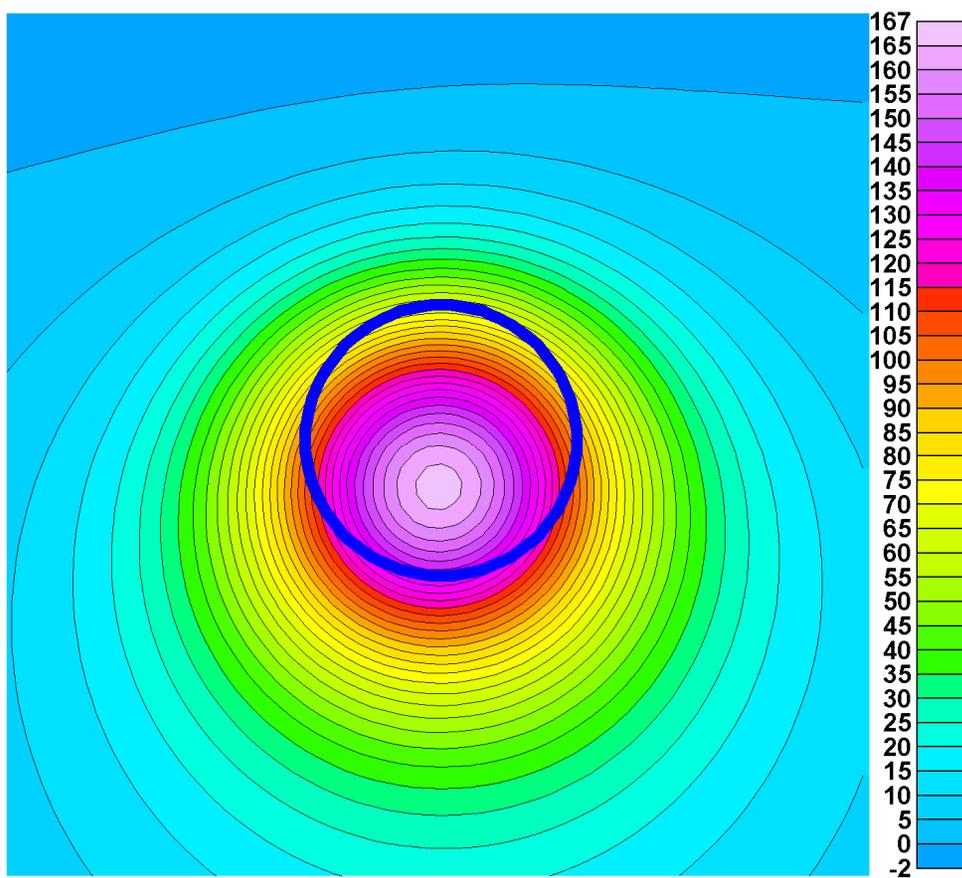
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# Keating Correlation for Kimberlite Pipes

- Technique developed by Pierre Keating (GSC)
- Applied to gridded magnetic data using a moving window
- Compares the response due to a model kimberlite pipe (or data over a known pipe) with field data, and determines the correlation coefficient centred on each grid cell
- High correlation coefficients are plotted, and cluster over pipe-like responses
- May locate alternative sources (e.g. gabbro plugs)
- Can be applied using total magnetic field, analytic signal, first vertical derivative, etc.

# Keating Correlation for Kimberlite Pipes



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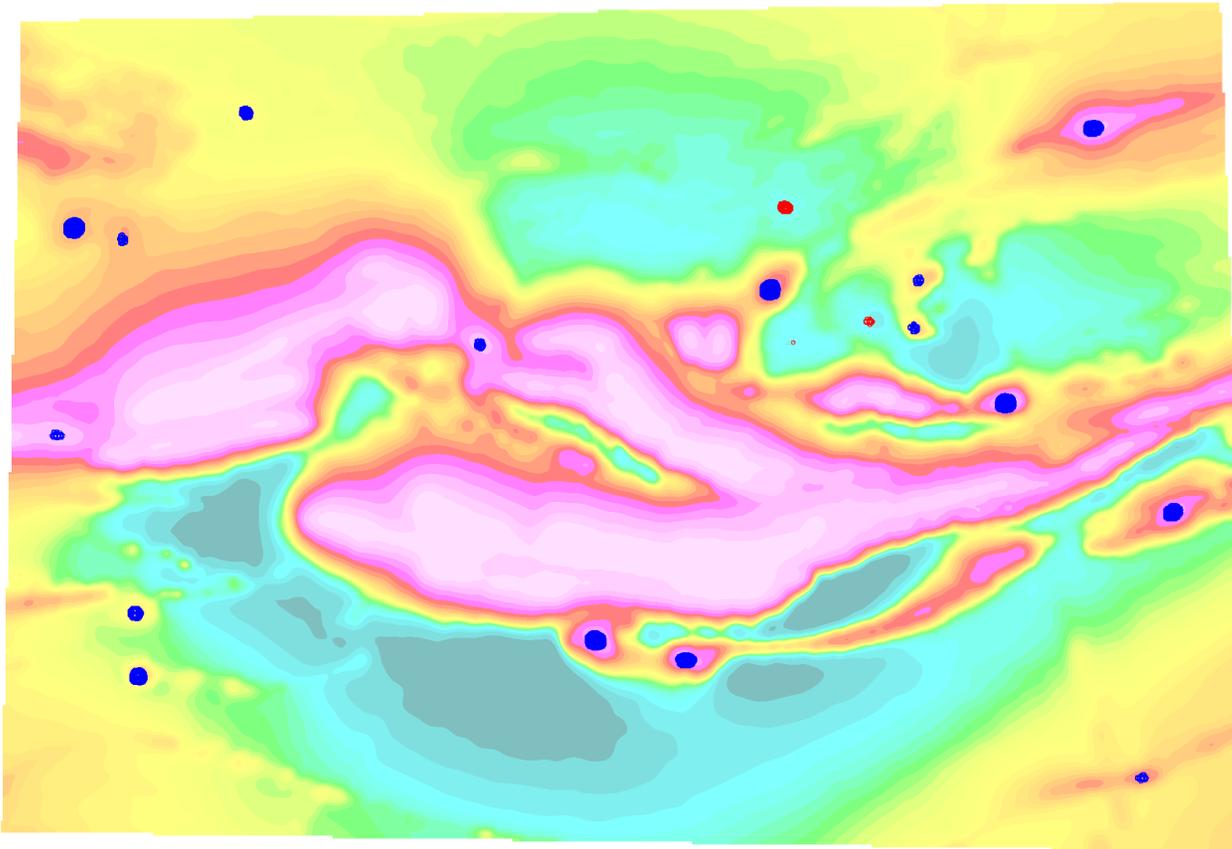


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# Keating Correlation for Kimberlite Pipes

Over total magnetic field



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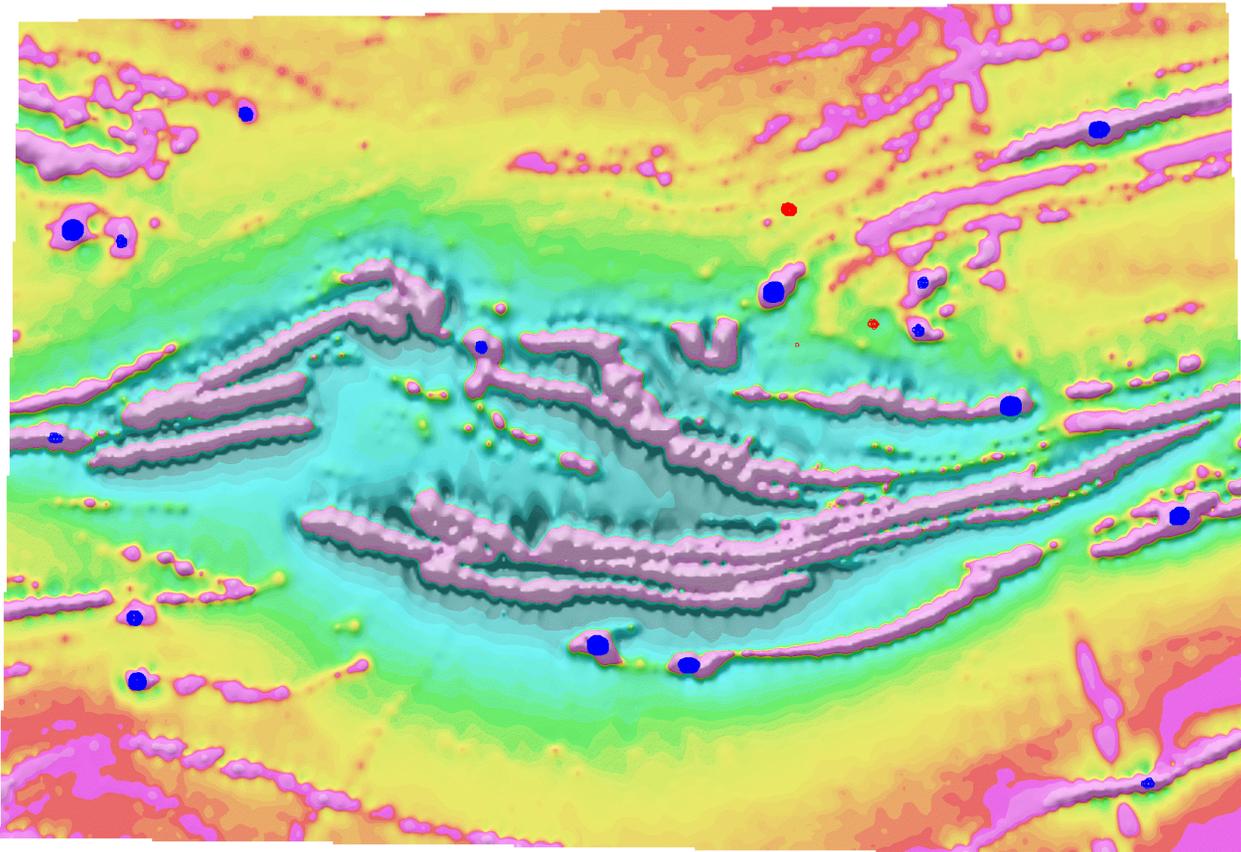


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# Keating Correlation for Kimberlite Pipes

Over first vertical derivative



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# Senegal Airborne Geophysics

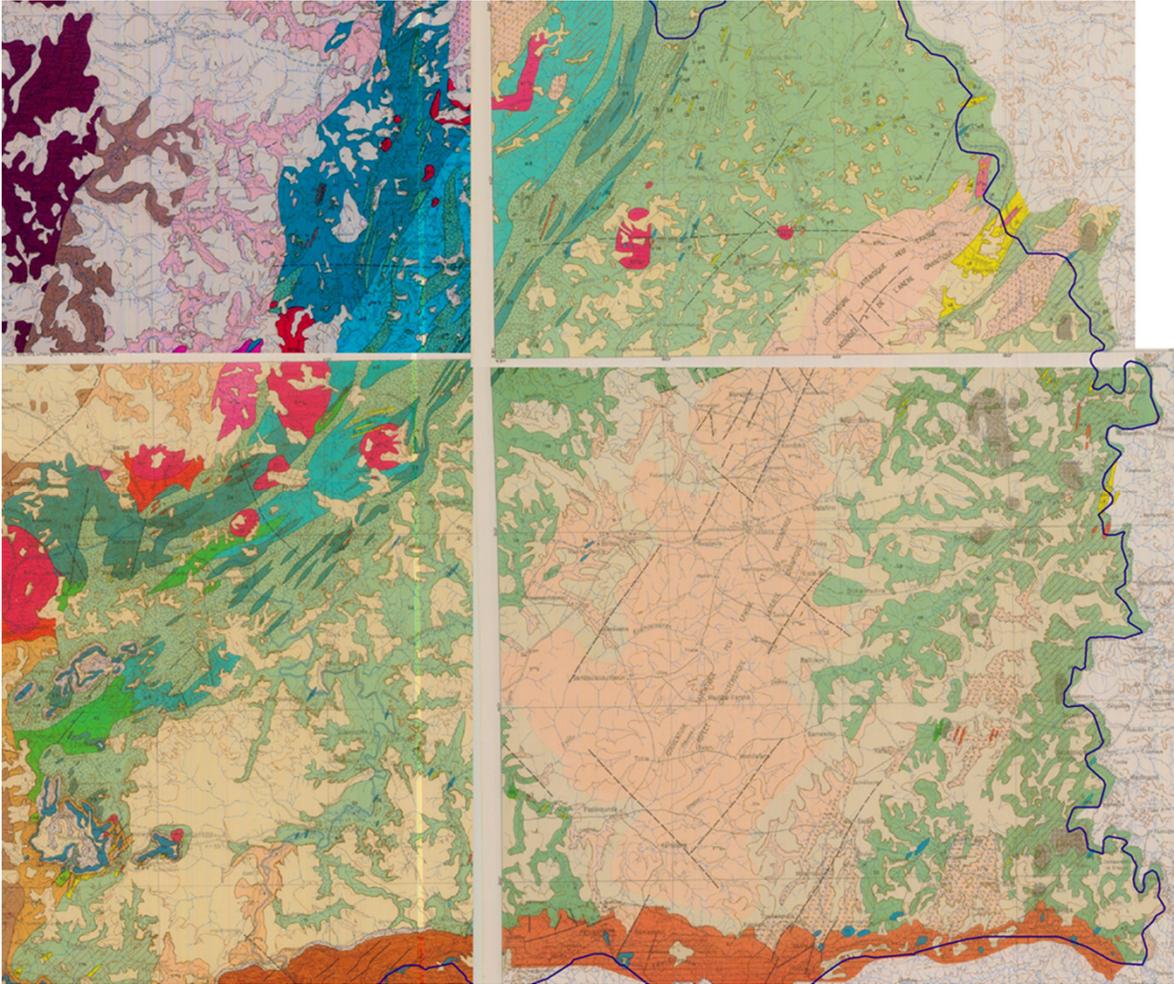
- Flown by Fugro Airborne Surveys
- Mag/Spec – totaling 133,800 km
  - 250 m line spacing
  - Horizontal magnetic gradiometer
- TDEM – 3 blocks totaling 22,800 km
  - TEMPEST CASA
  - 400 m line spacing
  - No mag or tie lines



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# Senegal - TDEM Blocks 1 and 2



200K Geology (1960's)

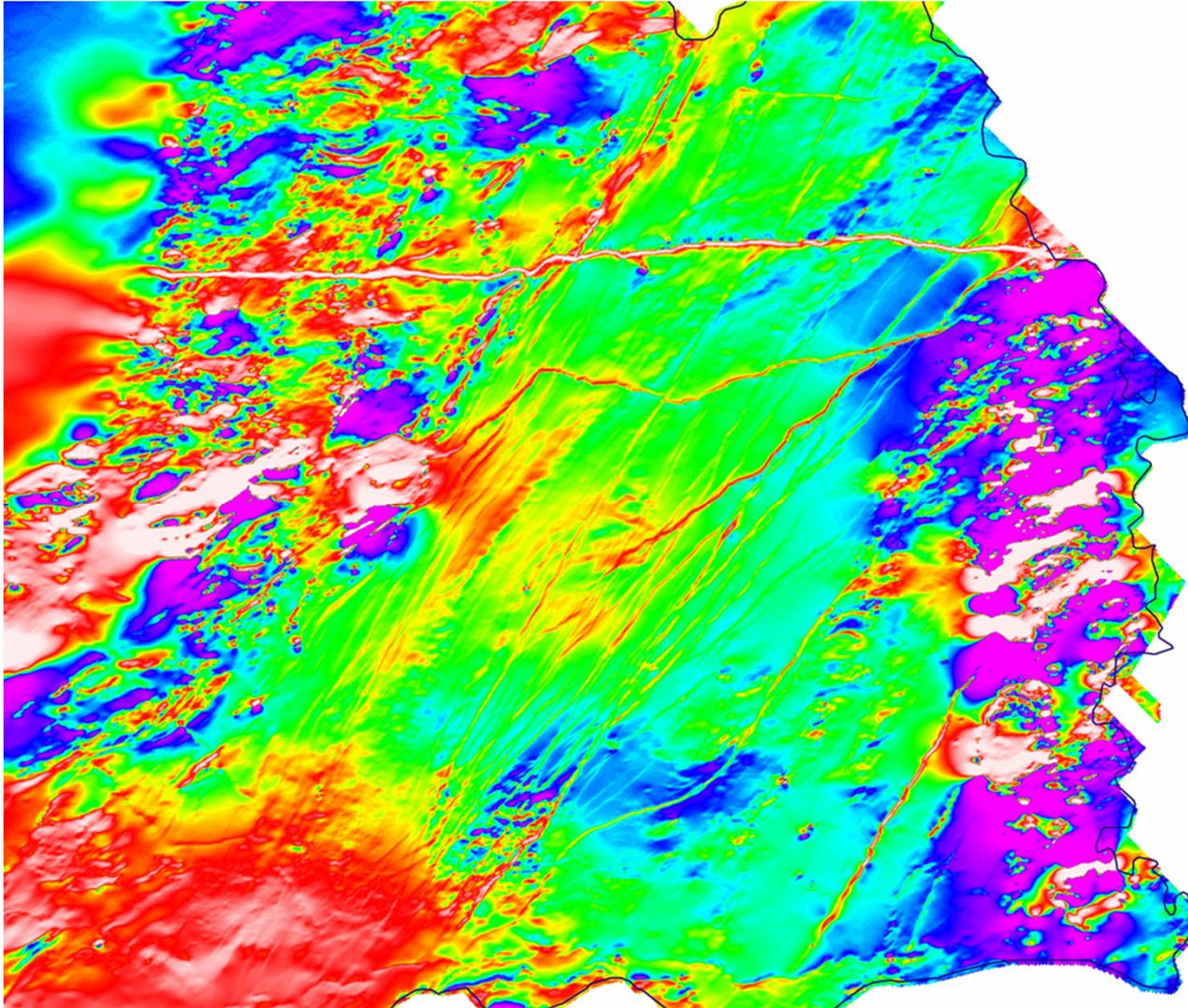
– Prolific gold belts extending into Mali



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# Senegal - TDEM Blocks 1 and 2



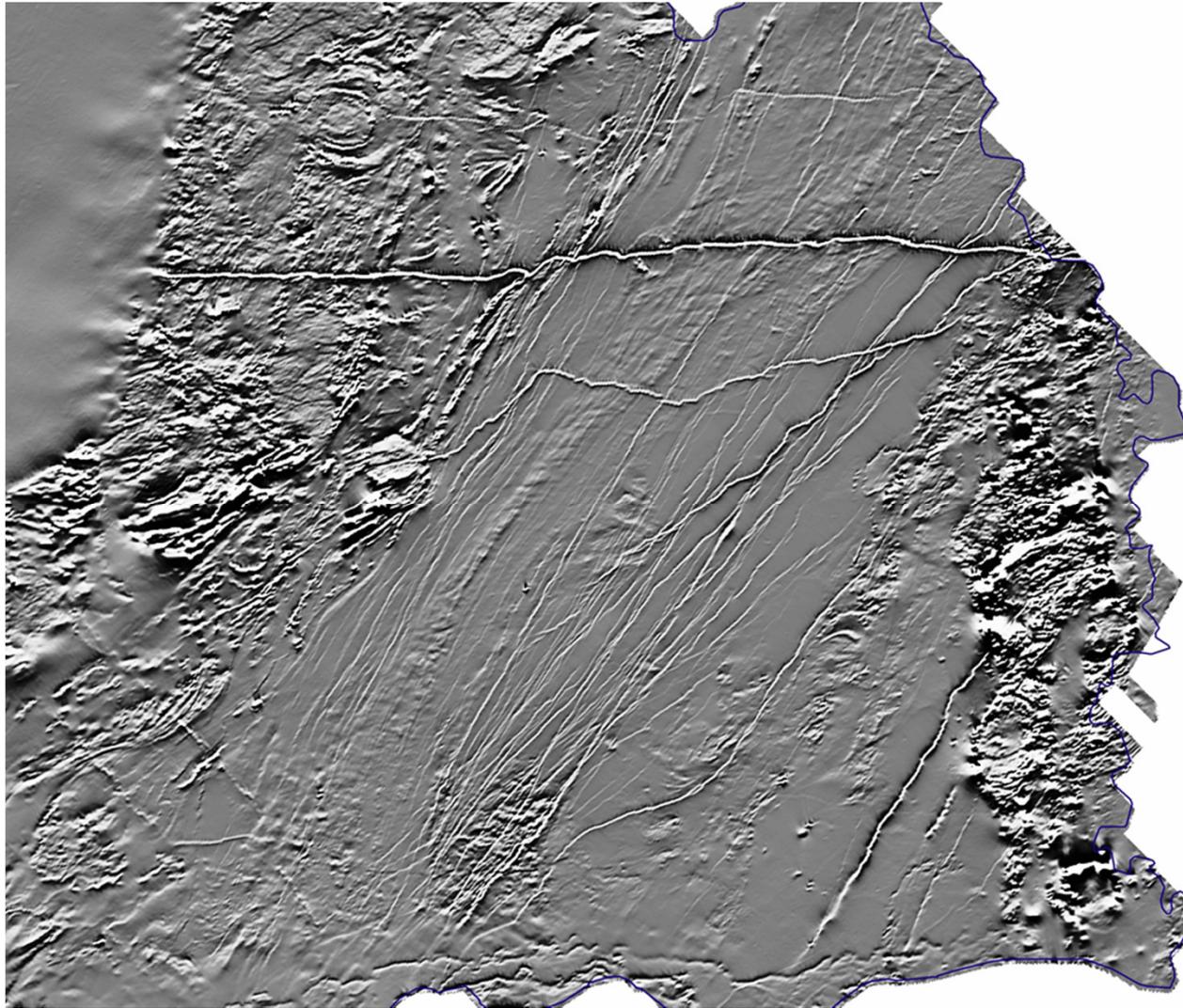
Pole-reduced magnetic field



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# Senegal - TDEM Blocks 1 and 2



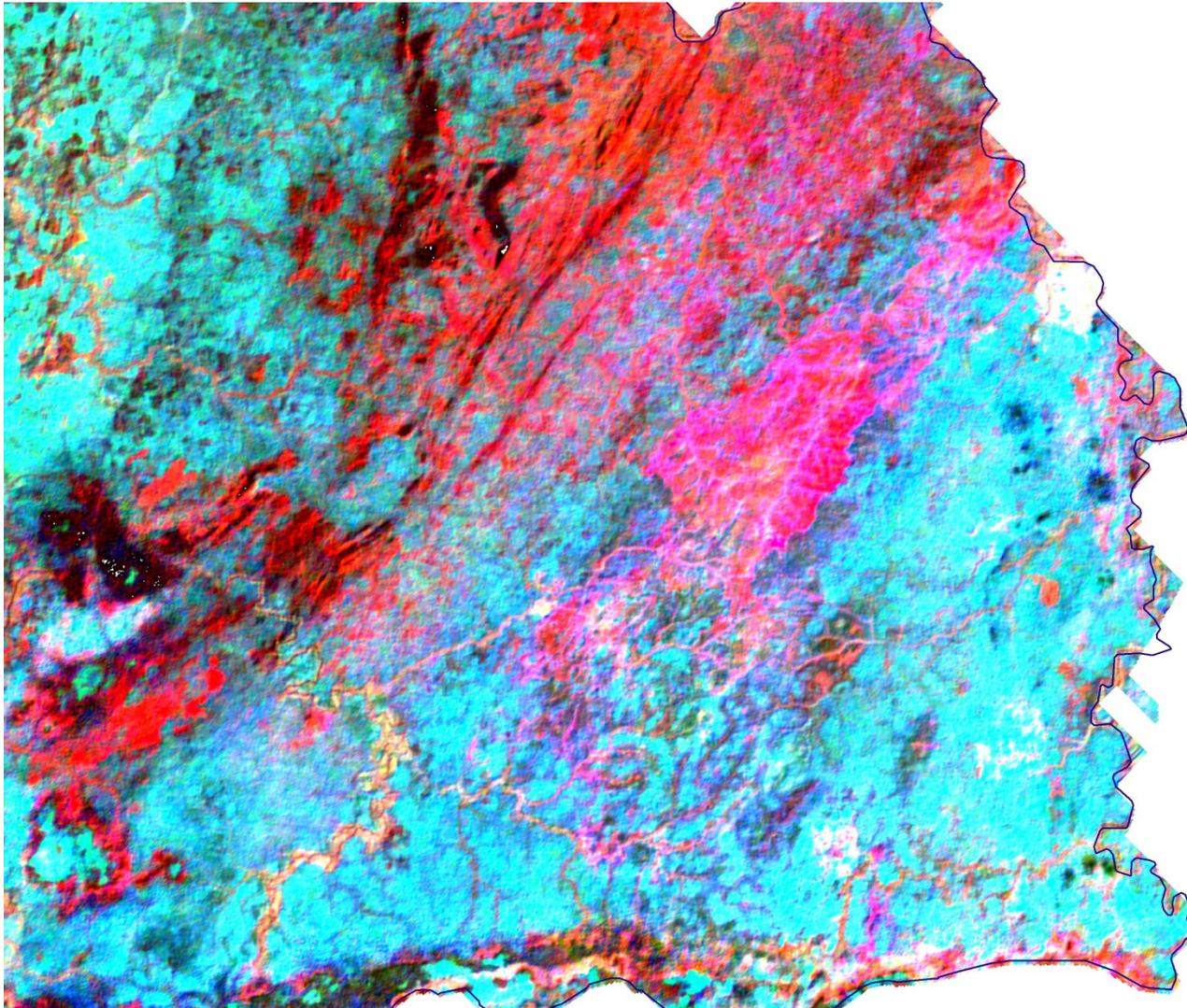
1VD of RTP



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# Senegal - TDEM Blocks 1 and 2



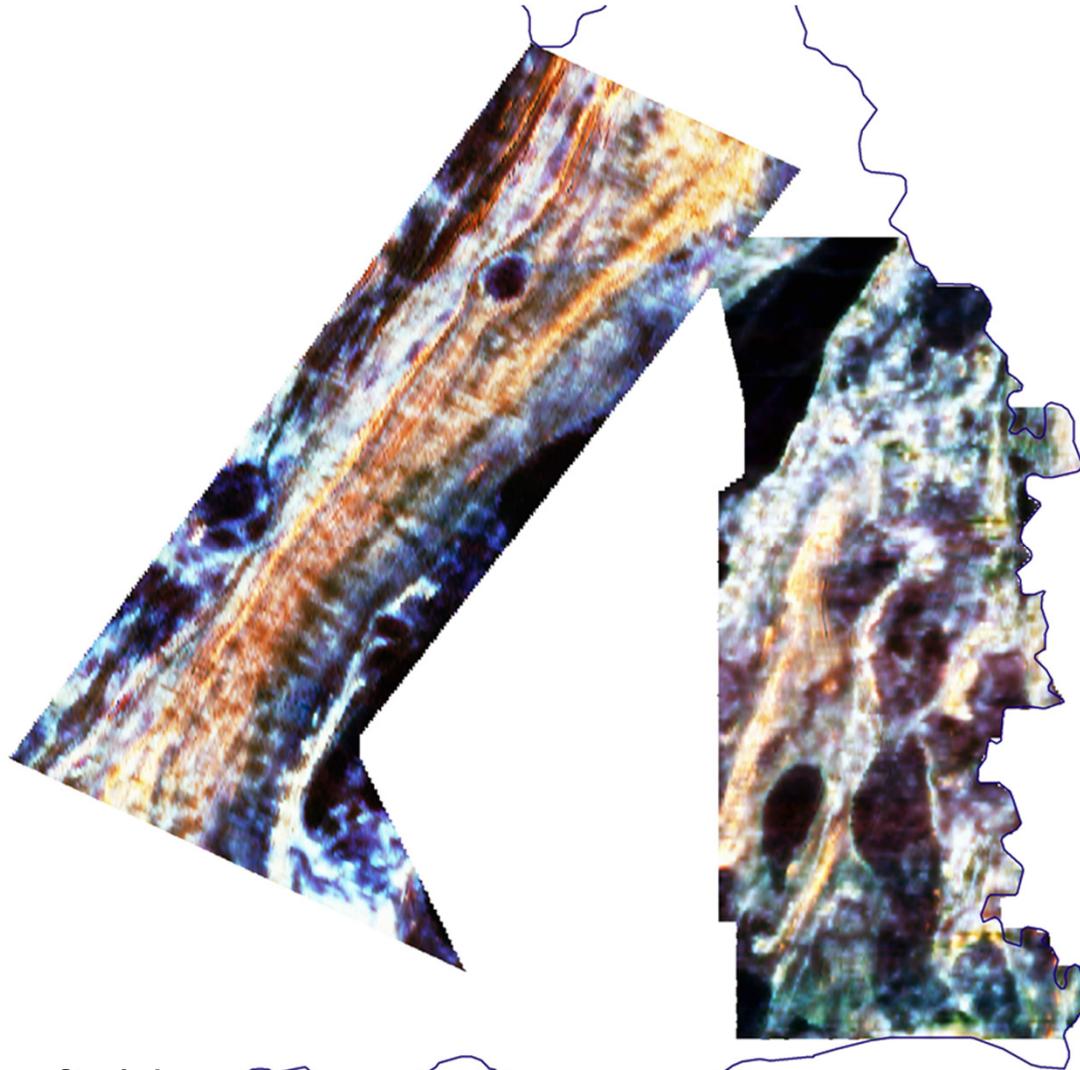
Radiometric Ternary Image: RGB = K-Th-U



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# Senegal - TDEM Blocks 1 and 2



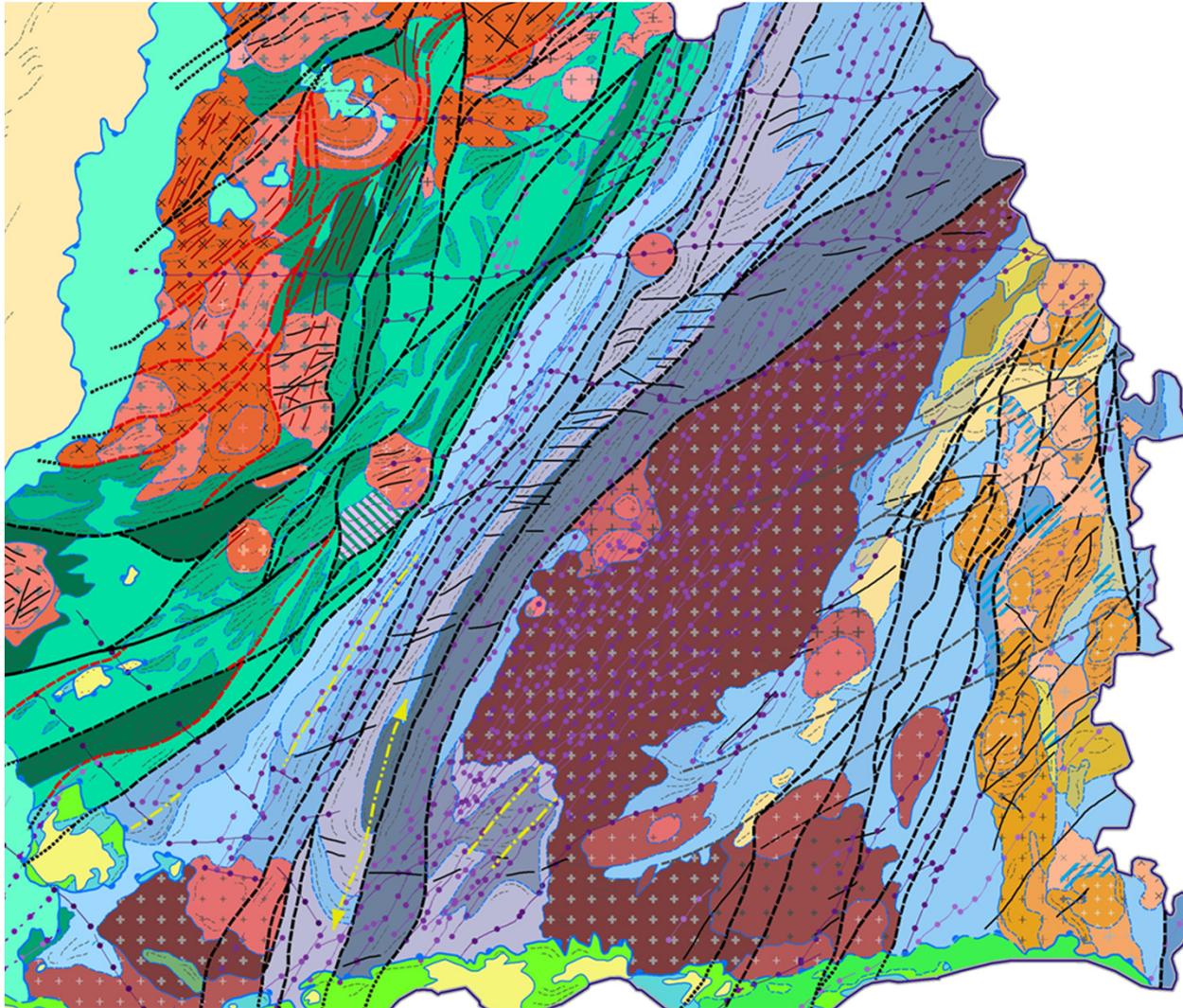
B-field Z-component Ternary Image:  
RGB = Late-Mid-Early Time



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# Senegal - TDEM Blocks 1 and 2



Integrated Geophysical Interpretation (Fugro, 2008)



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# Senegal - TDEM Blocks 1 and 2

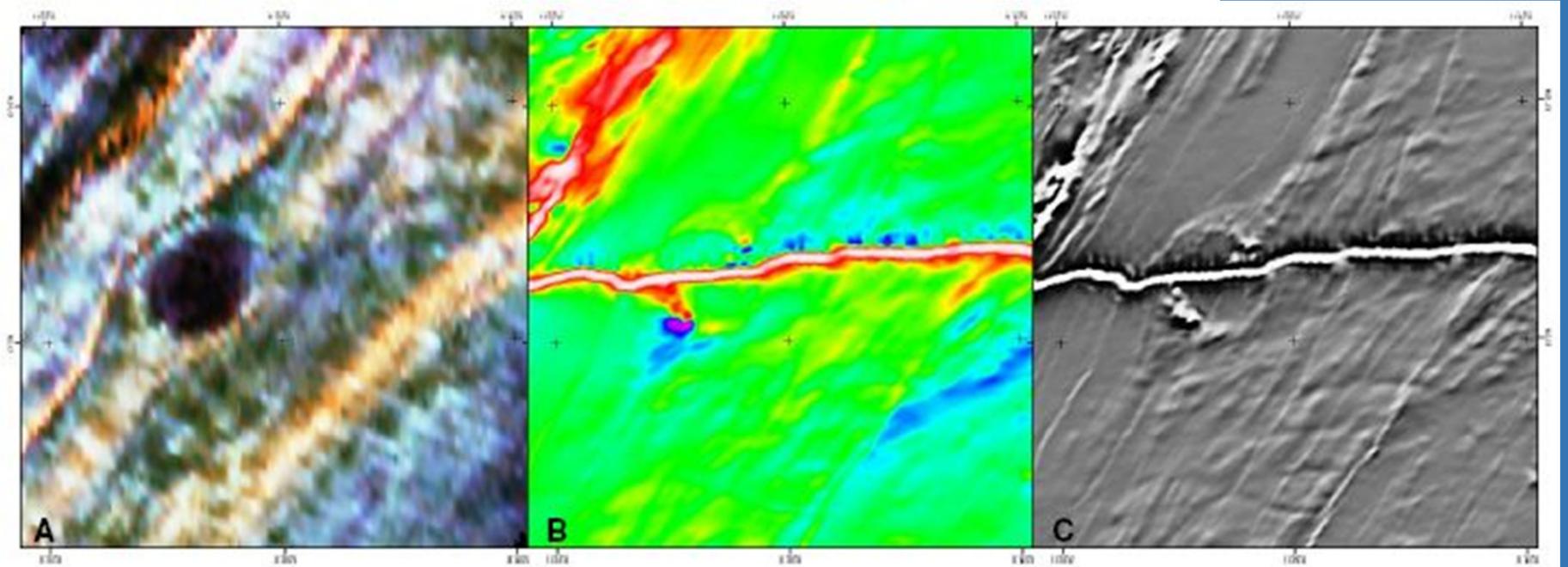
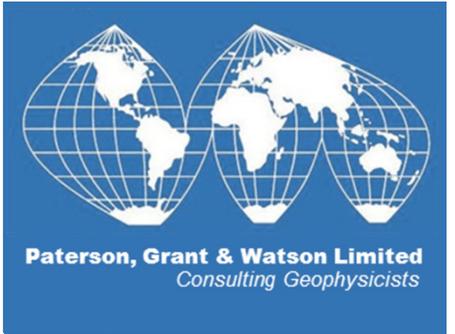


Figure 7.11: Grid images of EM ternary image (A), LLRTP TMI (B) and 1VD LLRTP TMI (C).

Intrusion best imaged in EM data – gold target

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# Ring of Fire Geophysics

- Flown by Fugro Airborne Surveys for GSC and OGS – McFaulds Lake survey
- Mag/AGG – totaling 19,700 km
  - 250 m line spacing
  - 100 m height
  - NW-SE line orientation

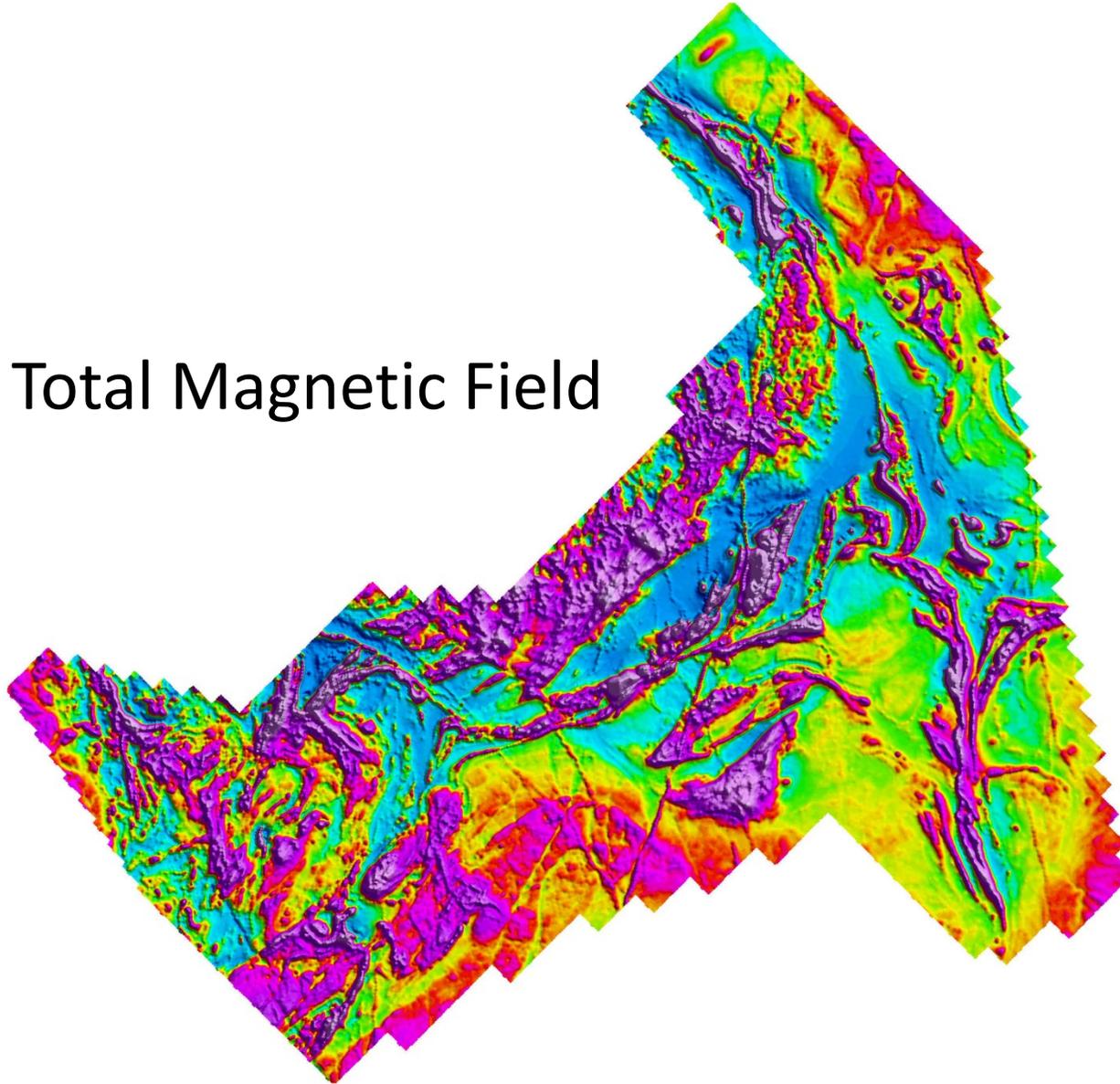


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# Ontario – “Ring of Fire”

Total Magnetic Field

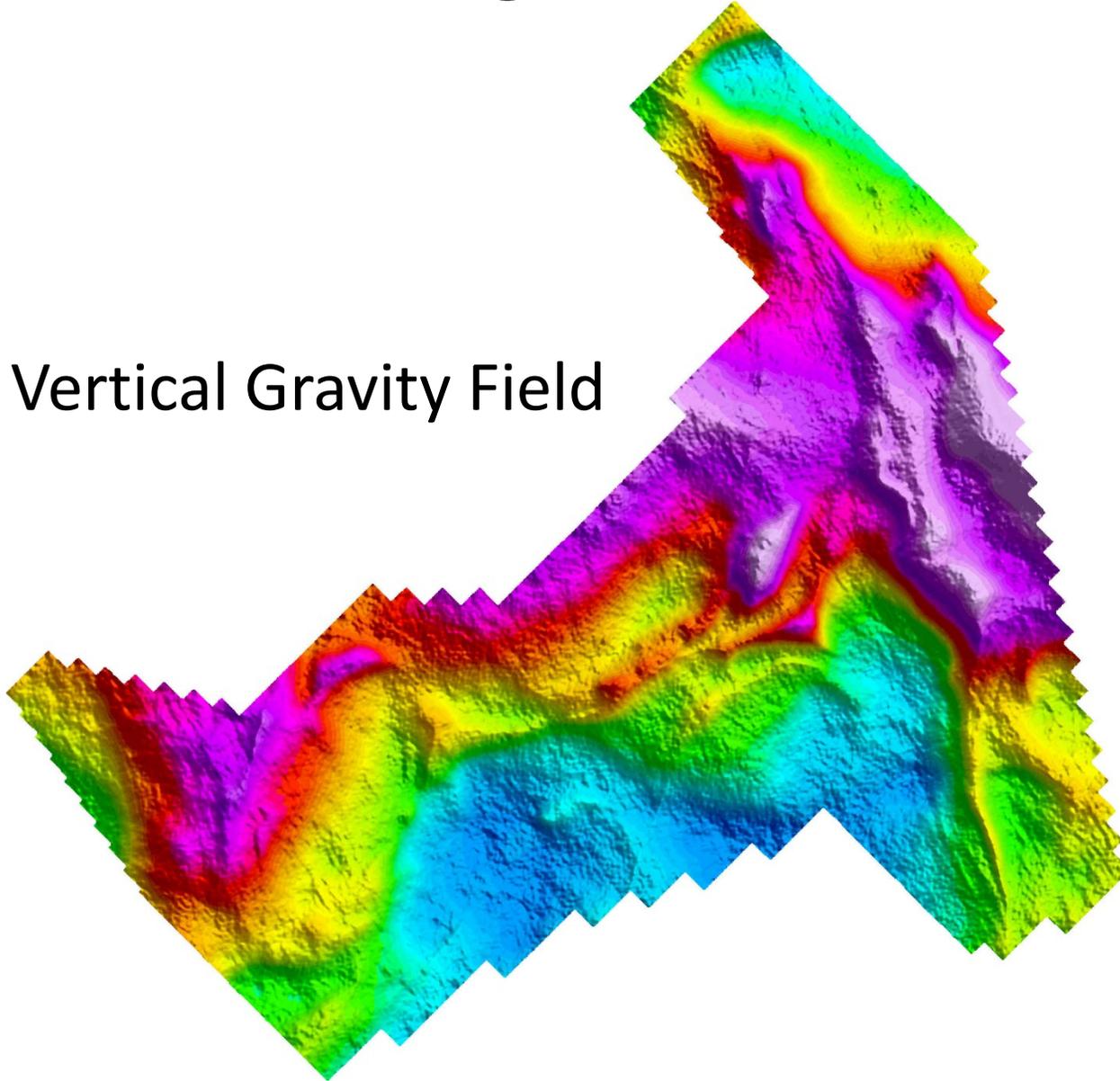


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# Ontario – “Ring of Fire”

Vertical Gravity Field

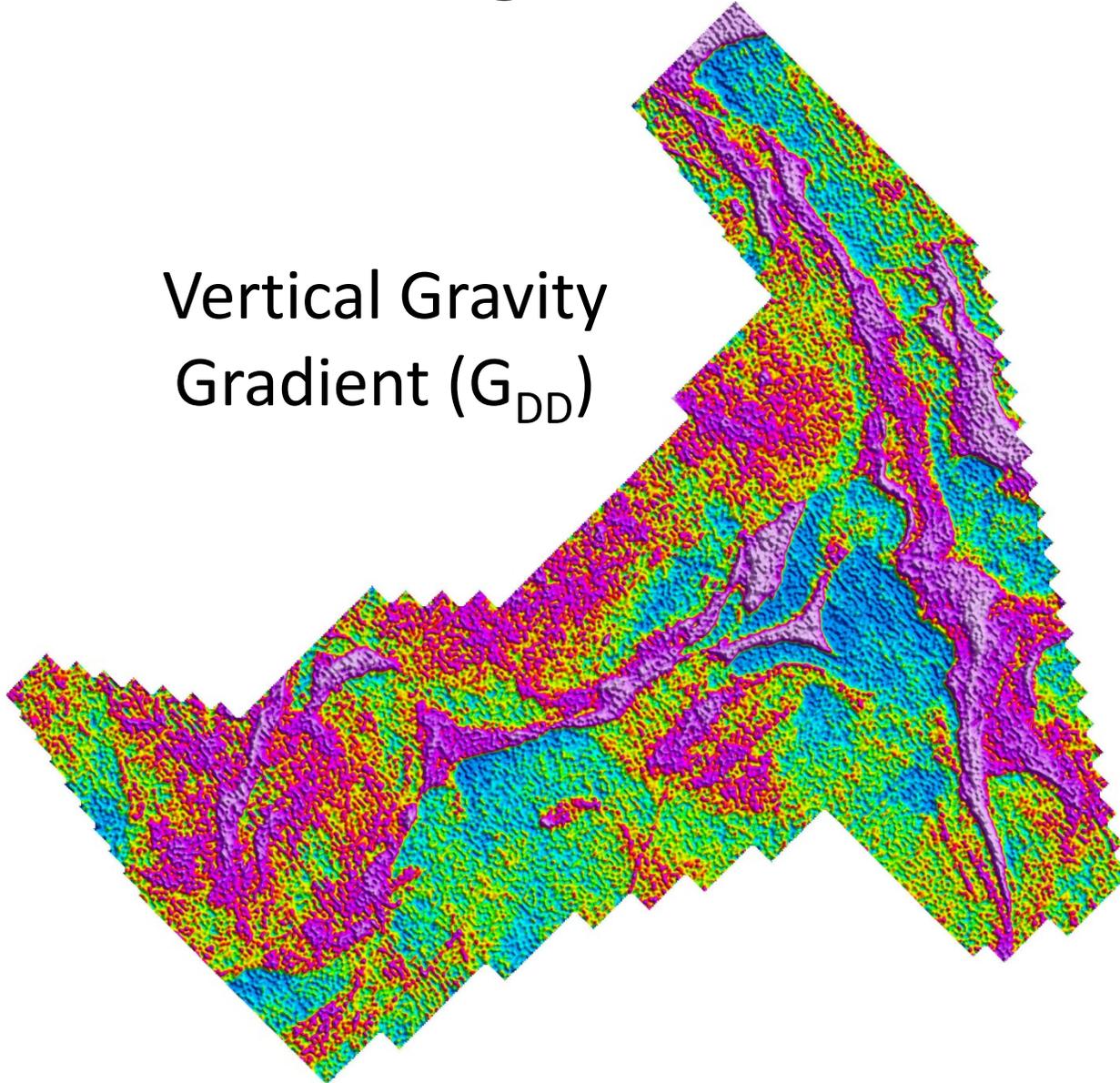


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# Ontario – “Ring of Fire”

Vertical Gravity  
Gradient ( $G_{DD}$ )



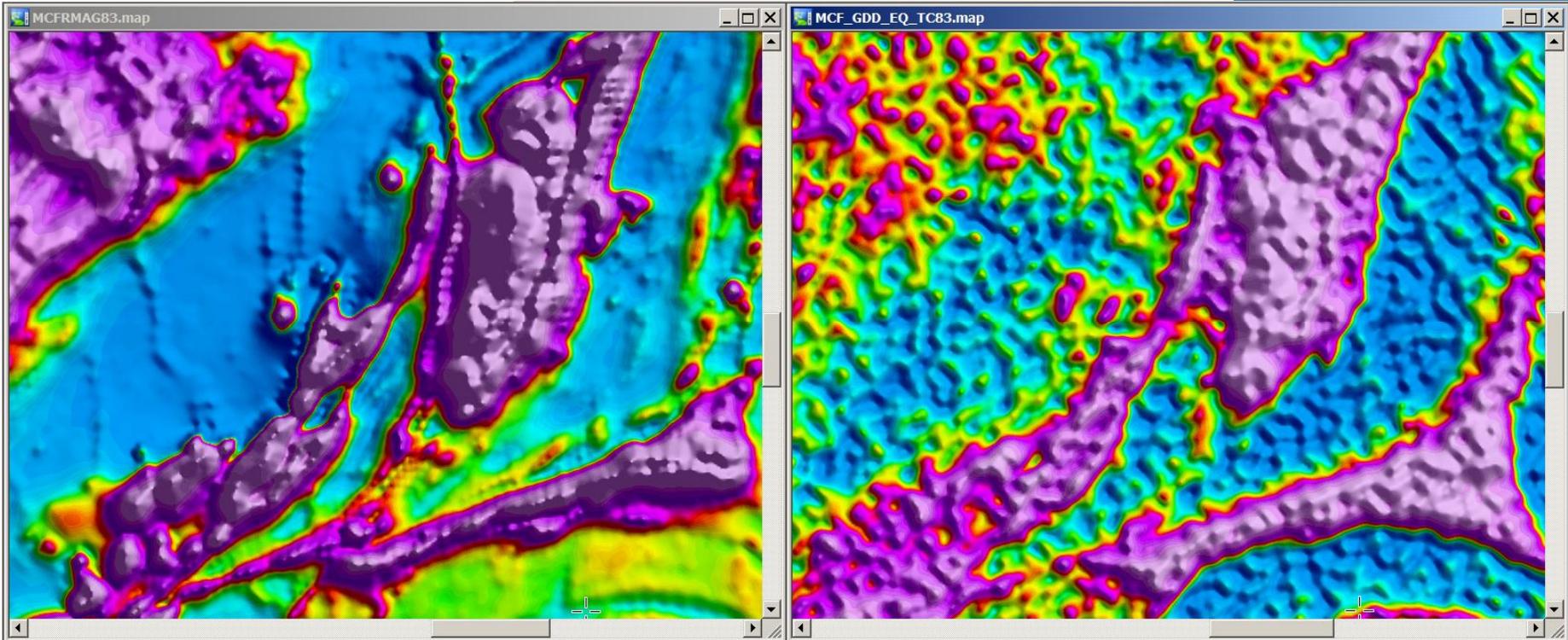
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# Ontario – “Ring of Fire”

TMI

$G_{DD}$



Imaging magnetic and AGG data concurrently adds discrimination of lithology, structure and targets

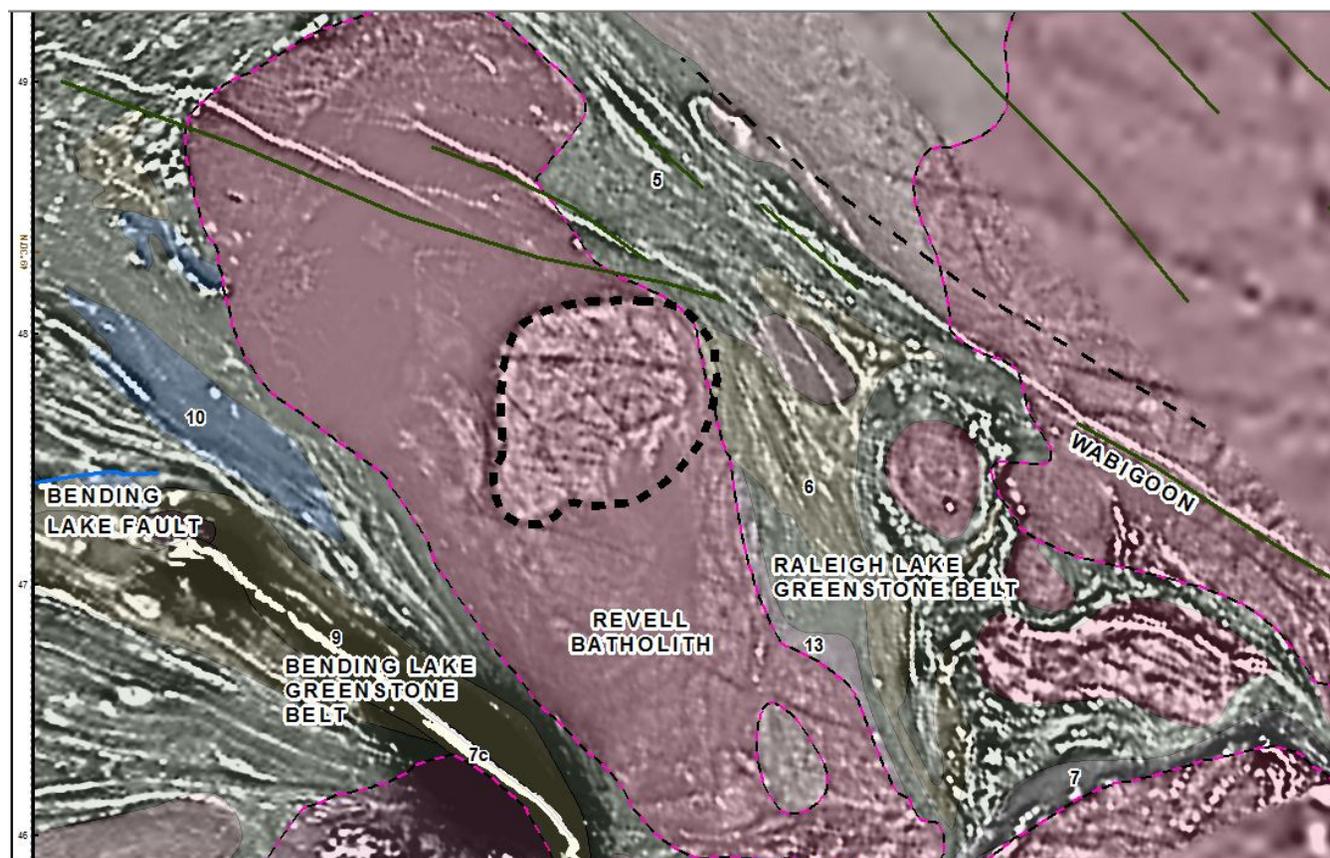
# Other Types of Presentation

- GIS – assemble geophysical layers with other geoscience data e.g. geology, geochemistry, topography, satellite imagery
  - Incorporates grid imaging
  - Facilitates integrated interpretation, classification, data mining
- 3D
  - Images on relief surfaces
  - View data together with models, drillholes, volumes, etc.

# GIS – Mapped Geology Over Magnetic Image



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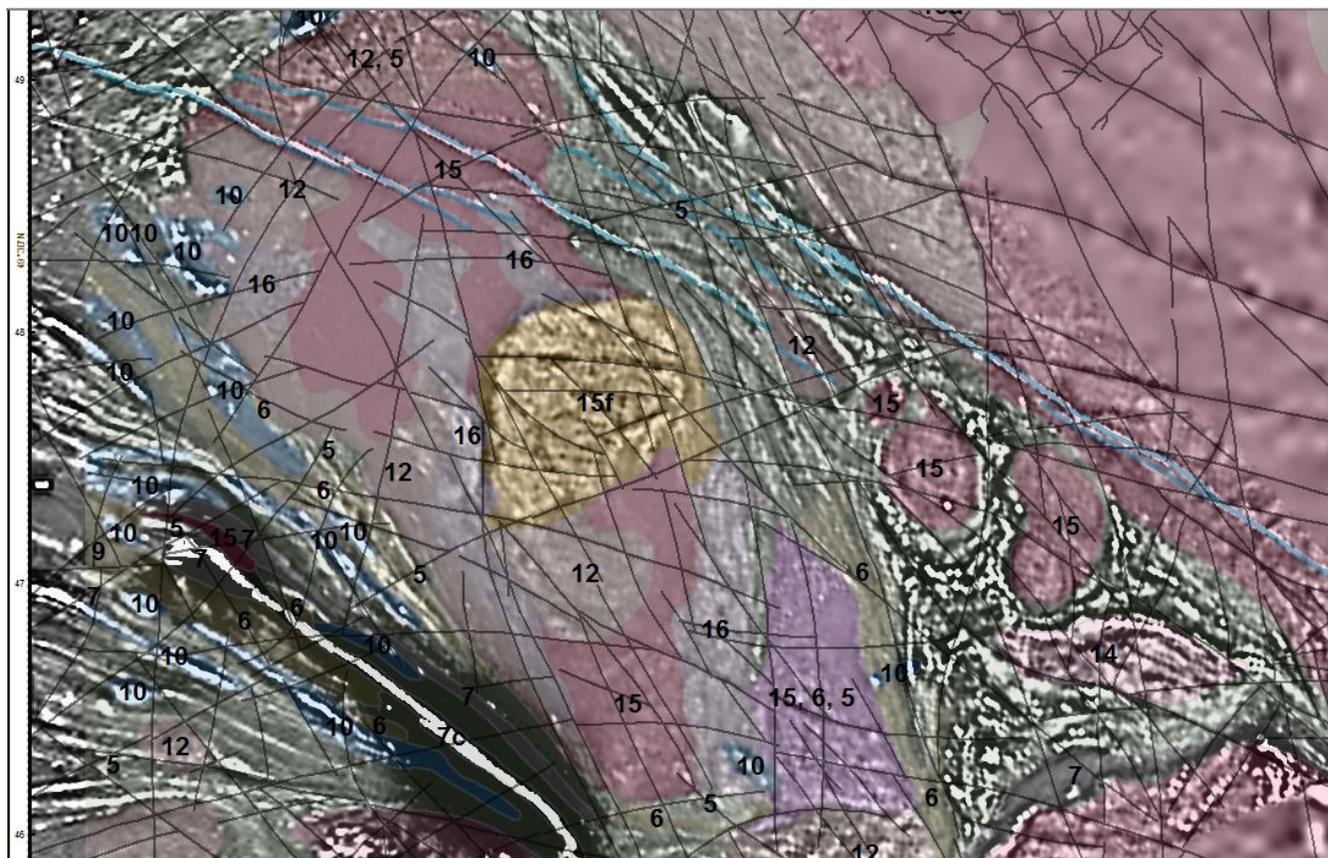
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# GIS – Geophysical Interpretation Over Magnetic Image



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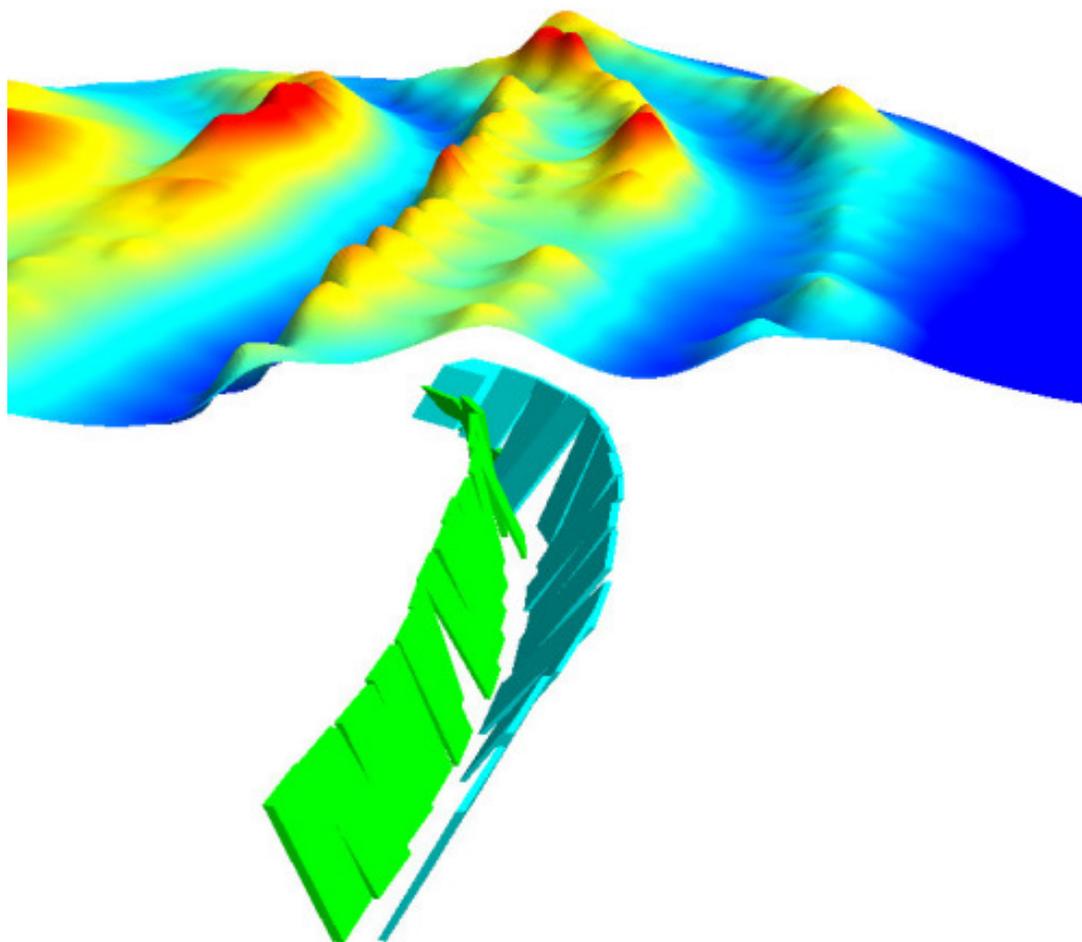
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# 3-D Presentation – Magnetic Data and Model

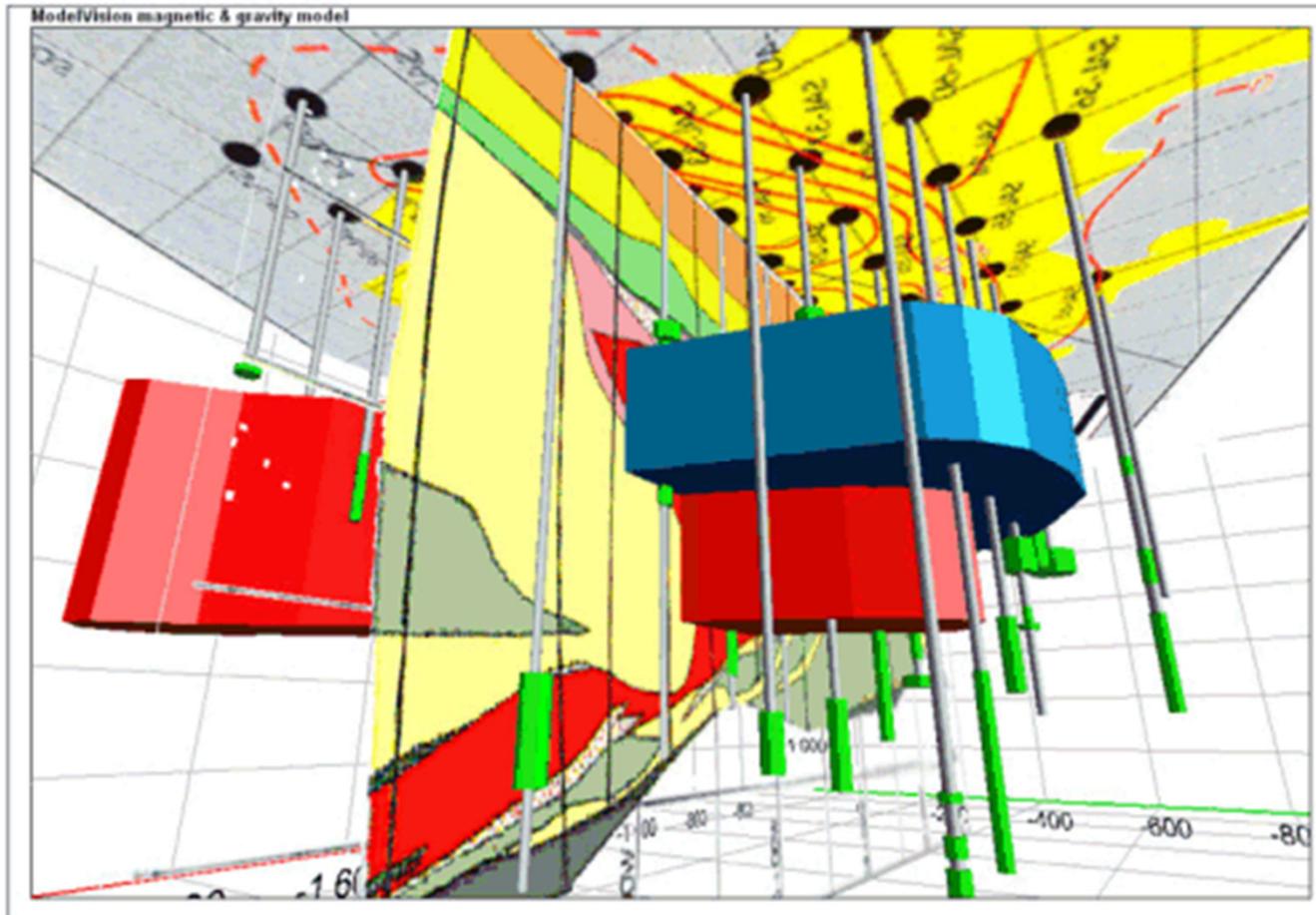


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# 3D Presentation – Constrained Inversion with Drilling



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# Software

- Geosoft OASIS montaj
- Pitney Bowes (Encom)  
Profile Analyst
- ArcGIS



# Websites

- Geological Survey of Canada Geoscience Data Depository including magnetic, gravity, radiometric and electromagnetic grids and surveys:  
<http://www.nrcan.gc.ca/earth-sciences/products-services/geoscience-data-repository/11818>
- OGS Earth including airborne surveys and grids:  
<http://www.geologyontario.mndm.gov.on.ca/>
- Best review of airborne magnetics and radiometrics from acquisition to interpretation (AGSO Journal, v. 17, no. 2):  
[https://www.ga.gov.au/products/servlet/controller?event=GEOCAT\\_DETAILS&catno=22887](https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=22887)
- International Atomic Energy Agency manual on radiometric surveys:  
[http://www-pub.iaea.org/mtcd/publications/pdf/te\\_1363\\_web.pdf](http://www-pub.iaea.org/mtcd/publications/pdf/te_1363_web.pdf)

